A Modular Control System for Remote Subsea Equipment

by

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Abstract

Title: A Modular Control System for Remote Subsea Equipment

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The following details the design of an expandable control system for use on remotely operated tooling and vehicles for the subsea industry. The main objective is to develop a basic control module which uses "off the shelf" microcontroller technology and allows for the ability to connect modules together with little hardware and/or software modification. A basic control module was developed that uses commercially available microcontroller technology as a foundation. This baseline system can be used singularly to control a simple oil field intervention tool, or in multiples, and applied to a full work class ROV.

After a review of related ROV technology, the development of the software is detailed and the resulting baseline system is described including hardware such as the microchip, I/O capabilities and power requirements. To aid in this description, an application of the system integrated with a subsea, oilfield tool is demonstrated.

Finally, a theoretical layout of a full scale ROV consisting of multiple nodes exhibits the advantages of this design. The modular capabilities are based on existing industrial technology and the use of microcontrollers enables a more efficient design.

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List of Keywords

CAN

Control Area Network

Control network system

Industrial control

Microcontroller

Remotely operated vehicle

ROV

Serial Bus

“Smart” tooling

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Chapter 1
Introduction

Remotely Operated Vehicles (ROVs) have become the instrument of choice for performing deep water work and research. Due to the increasing operational depths as well as the cost and complication of sending a person (diver or manned submersible), it is much more practical to use an ROV. These vehicles consist of multiple subsystems and add-on specialty tools which must be operated from a surface control station. As the tasks the ROV is required to perform grow more complicated, the control system must evolve as well.

This thesis describes the design of a control system for remotely operated, subsea tooling that can also control a work class ROV (see Figure 1.1). A basic system that can be expanded modularly without complicated software or hardware changes was designed. This was accomplished by the selection of proper components and suitable programming techniques. The central processing unit (CPU) selected was the Motorola DSP56F805 because its functions fit the project requirements as will be seen in Chapter 3. The C language was used along with the Motorola DSP (digital signal processor) libraries to create portable and easily understandable code. Finally, the Control Area Network (CAN) provides the networking ability that allows basic control modules to be chained together for more complicated control solutions

This system was developed to control a subsea torque tool (Figure 1.2) that is an ROV operated tool found in the offshore oil industry. Torque tools are hydraulically driven tools used to open or close subsea valves and perform tasks requiring a rotational motion (see Glossary for a more thorough definition). Most torque tools in use today do not have a dedicated control system and are operated with spare solenoid (on/off) valves from the host ROV. These tools are prone to

damaging equipment because of the lack of pressure and rotational speed control. The torque on these tools is set by way of a pressure relief valve supplying hydraulic pressure to the torque motor. These relief valves must be set on the surface. With the use of a control system that includes proportional speed and force control with feedback, the tool becomes much more versatile. The pressure (and therefore torque) may be set through the control interface preventing unnecessary recoveries to the surface. The speed may be controlled proportionally to prevent damage and accelerate operation times.

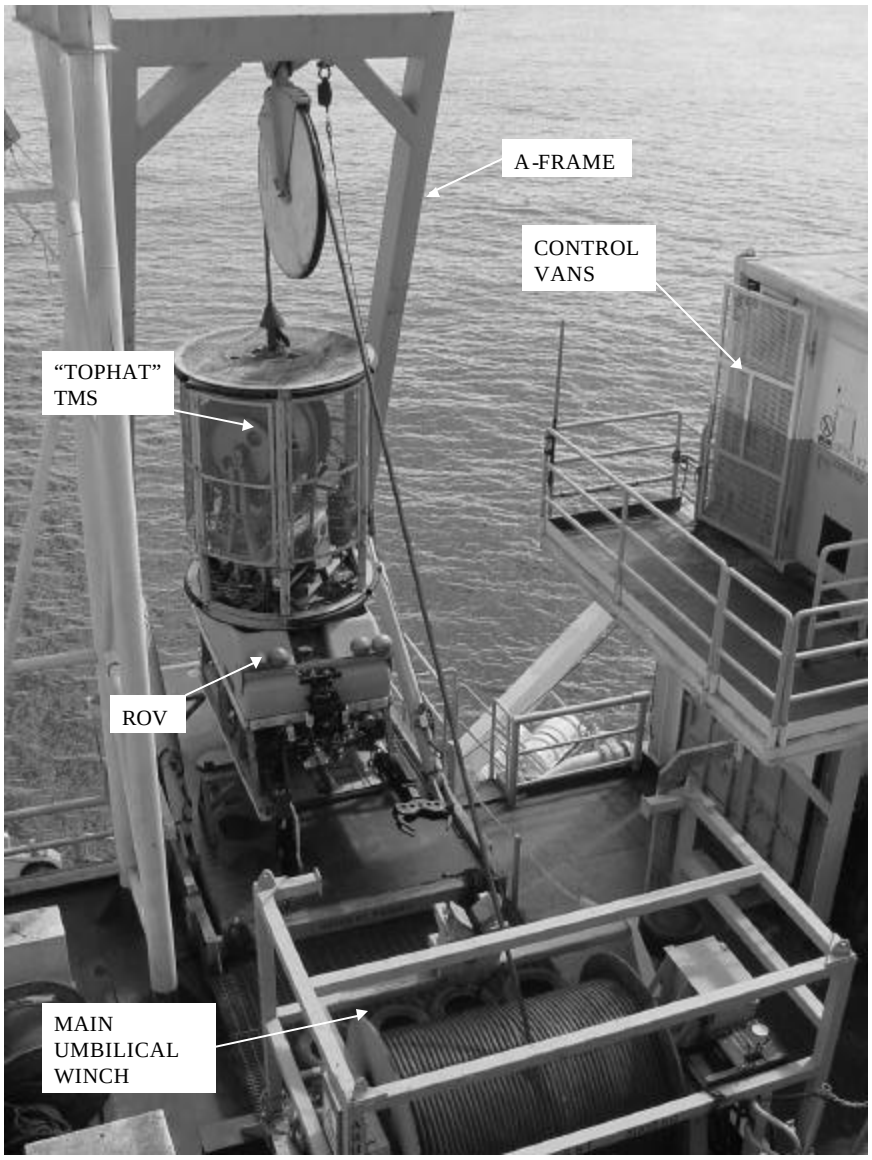


Figure 1.1: Work-Class ROV System with Deck Components

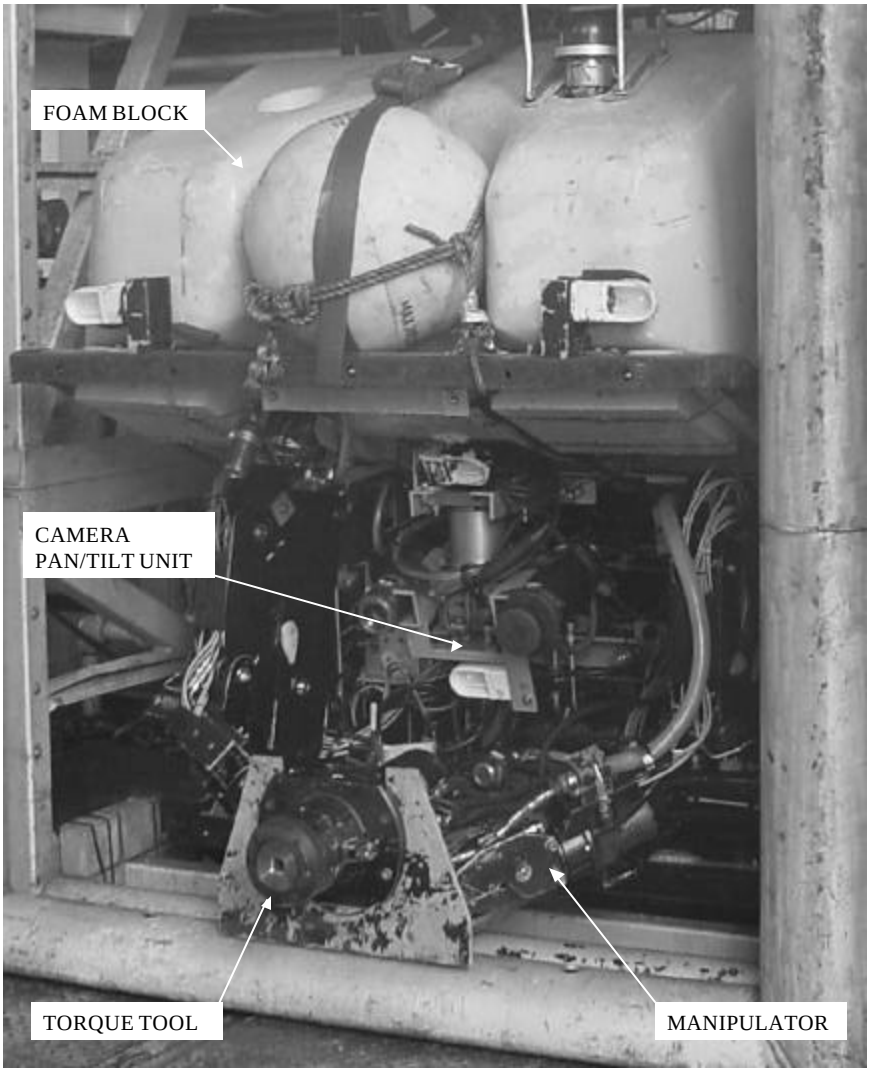


Figure 1.2: Work-Class ROV with Torque Tool

There are vast numbers of specialty tools that have been designed for ROV use ranging from cable burial jetting skids for the communication industry to XYZ, 3 axis alignment systems used for precision tool guidance in the oil and gas industry. As these tools become more complicated, they begin to require their own control systems including analog and digital I/O (input and output), serial

communications, and processing power. A torque tool was selected since the requirements for this tool are representative of what is necessary for an ROV control system on a smaller scale. The control system designed in this thesis demonstrates serial communication (RS-232), digital I/O, and analog I/O. This paper will describe the progressive development of the software and then give a full explanation of the baseline control system as it is applied to the torque tool including the hydraulic manifold with valves, electrical layout, and C code.

A theoretical layout of an expanded system in a work class ROV will be described in the ending chapters. The baseline control system has been designed in such a way that it can be configured to control a variety of components required on an ROV such as valve packs, electric thrusters, camera pan and tilt units, etc. By linking these multiple control "modules" together with their associated hardware component, an entire ROV system can be assembled. The goal of this layout is to convey the advantages of using this expandable system and how it would be implemented.

A Brief Description of an ROV Control System

An ROV control system includes two discrete structures, a topside and vehicle or bottom side system connected by an umbilical (Figure 1.3). The topside system is the user interface and is made up of a graphical/video display and user controls such as joysticks, switches, paddles, etc. These user inputs are constructed into a data string that is transmitted to the vehicle via the umbilical. Any processing of data typically takes place on the topside controller/processor. The bottom side system receives the user inputs and executes the command via the various subsystems and components such as manipulators, thrusters, and cameras. It will relay information back to the topside unit including sensor data and current component settings (for instance the power setting of a particular thruster).

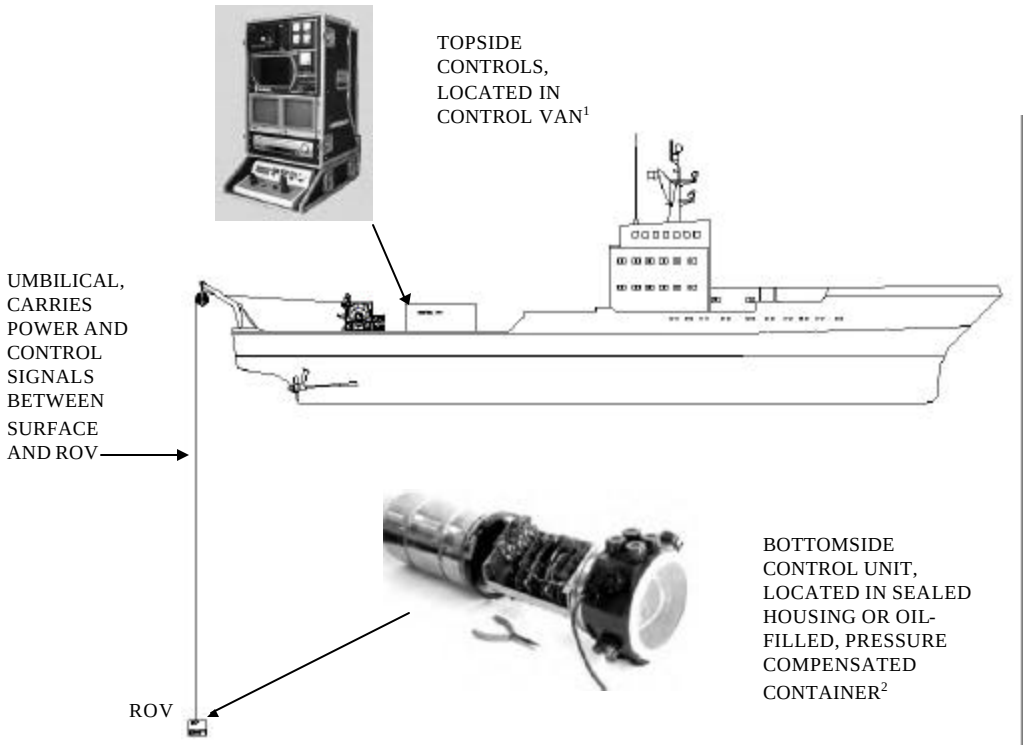

TOPSIDE CONTROLS, LOCATED IN CONTROL VAN[1]
UMBILICAL, CARRIES POWER AND CONTROL SIGNALS BETWEEN SURFACE AND ROV
BOTTOMSIDE CONTROL UNIT, LOCATED IN SEALED HOUSING OR OIL-FILLED, PRESSURE COMPENSATED CONTAINER[2]
ROV

Figure 1.3: ROV Topside and Bottom Side System Operated from a Ship

The topside control computer is generally a PC (personal computer) and therefore, runs a processor such as an Intel x86 or AMD type microchip. The bottom side CPU can be a microcontroller, Intel type processor, programmable logic controller (see Glossary), or a number of other industrial CPU's. There are many definitions for these different CPU types. In this thesis, microcontroller refers to a microchip which runs a set of embedded instructions and is often tailored to a specific application. A processor is equivalent to the CPU found in standard desktop and laptop computers and runs an operating system which governs processor usage. As a rule of thumb, processors typically run at higher

speeds, have a wider range of capabilities than a microcontroller, and are intended for use with peripheral devices.

An Introduction to the System

The control system designed in this paper uses a PC for the topside CPU and a microcontroller for the bottom side. The topside PC provides a platform which is familiar to the operator through the use of a Windows operating system. The selection of a microcontroller instead of a more powerful processor on the bottom side is due to limited requirements of the subsea portion of an ROV control system. The primary purpose of the bottom side controller is to act as a relay system. It must be able to receive and prioritize commands from the surface system, carry out the required functions via input/output (I/O) capabilities, and then deliver status information back to the surface. The testing of this control system on the Motorola DSP was completed in a step by step fashion. This means the software progressively incorporated more complicated functions. This allowed a comparison between the microcontroller running a single I/O function (such as turning an LED on and off) versus running the final product. There was no visible perception of a slow down in performance during this comparison.

The focus on software structure mentioned above is an attempt to use manufacturer provided libraries to create code that can be easily understood and modified. Many items on an ROV have identical functionality from a processing perspective. For example, an analog pressure transducer and an analog flow meter, each with an output range of 0 to 5 volts DC, would appear identical to the controller. Calibration of this data can occur on the topside processor allowing the operator to not only view useable information, but also use the raw data for diagnostic purposes. By following this methodology, generic subroutines can be developed that can be used for multiple purposes.

It should be noted that all programming in this design was done in the C language. Many microcontrollers in the past required a thorough understanding of Assembly code whereas the Motorola development environment provides the designer the choice of C, Assembly, or a mix of the two. Because C is widely accepted throughout the industry and a great deal of code is available as shareware, the use of the C language helps meet the design goals of being easily expandable, portable, and widely known.

An additional requirement was the ability to expand to accommodate a more complex system. To accomplish this, multiple microcontrollers are used instead of a single processor. The system bus selected for connecting these multiple nodes is the Control Area Network (CAN) protocol developed by Bosch. This was chosen because of its proven reliability in noisy, industrial environments. Each microcontroller is assigned a specific piece of equipment or set of equipment. For instance, one controller might be assigned a valve pack manifold which controls a robotic manipulator. Another might be assigned to control all the thrusters onboard. While another might control the movements of the camera pan and tilt units. These components can then be assembled to create a mission specific ROV. If mission requirements change, components can be added or subtracted as necessary.

Method of Writing and Organization

The layout of this paper is intended to allow the reader to duplicate, and in the process learn, the completed research. A list of software requirements necessary to control an ROV torque tool was assembled and then each of these was completed independently. The final baseline system was a result of combining these individual sections of code. This method worked because it allows the developer to become familiar with the controller and development environments by

completing small tasks one at a time. It also encourages the use of organized and methodical programming techniques to meet the software structure goals mentioned above.

Another benefit of this approach was the chance to observe the differences in controller response between simple applications and the final system which includes prioritized multi-tasking. It was this comparison that confirmed the processor was capable of performing the application rapidly and that it did not display any noticeable lag in response time.

The final layout of the expanded system as applied to an ROV is theoretical and serves as grounds for further research and development. This description was influenced by insights gained in the development of the baseline system, research into the CAN protocol, and field experience gained while working with and designing ROV systems for the offshore oil and gas industry.

This thesis is organized into ten chapters, eight appendices, and a glossary. Chapter 1 is an introduction that gives a general overview and objectives for the research. Chapter 2 presents an in-depth review of existing ROV technology to determine why this research is unique and worthwhile. Chapter 3 explains the reasoning behind the selection of the Motorola DSP microcontroller and the CAN bus system. Chapter 4 describes the step by step method of the software development. Chapters 5, 6 and 7 explain the finished product including the hardware (valve pack, controller card and hydraulics), the bottom side C code, and the topside user interface that was programmed in LabView. Chapter 8 is a review of the Control Area Network protocol developed by Bosch. Chapter 9 describes how the CAN system and Motorola's MSCAN can be used to develop an expanded system based on the control system described in chapters 5, 6 and 7. Chapter 10 is the conclusion that reviews the research and explains why the original objectives were met. The appendices contain the C code from the initial development and the final baseline system, the mechanical drawings for the construction of the valve

pack, an electrical schematic of the controller board, and a hydraulic schematic of the baseline control system as applied to the torque tool. A glossary can be found at the end that contains definitions of many of the technical terms and abbreviations used in this thesis.

Chapter 2
Overview of Related ROV Technology

Remotely Operated Vehicles of the World lists 123 companies and institutions that manufacture remotely operated vehicles.[1] They range from the world renowned Woods Hole Oceanographic Institution (WHOI), who can claim such successes as the discovery of the wreck of the HMS Titanic, to Seaeye Marine, which manufactures small electric ROVs. This chapter will review these groups and determine whether the control system designed for this thesis is unique when compared to existing technology.

ROV control systems are as numerous as the manufacturers themselves. They include PC-based systems and those using microcontrollers such as PIC and Zilog. A number of these control systems are considered modular or expandable. However, these systems were designed with different goals in mind and resulted in products that do not meet the design parameters of this research. The system described in this research is intended to control a simple ROV tool. It would be beneficial for the baseline control system to maintain a small size in order to be accommodated on a variety of ROV sizes. This baseline system should have the ability to be chained together in multiples to control a more complex system such as a work class ROV. To accomplish this, the Control Area Network bus has been selected.

This chapter will answer the following two questions:

Are there similar systems out there?

If so, what sets this project apart to warrant even doing it?

Industrial ROV Manufacturers:

ALSTOM SCHILLING ROBOTICS –

Figure 2.1: ALSTOM Schilling Quest Electric ROV[2]

ALSTOM Schilling Robotics is based in Davis, CA and was founded in 1985. They are known for the design and production of ROVs and ROV components, particularly robotic manipulators. Their introduction of the Quest (Figure 2.1) all-electric ROV was one of the larger innovations in the ROV industry in recent years. Some of the ideas it presented:

Central, expandable telemetry hub allows for increased control system capacity/modularity.

SeaNet connectors with PIC Chip based logic are common to all items.

Logic connectors and visual software combine for a plug & play effect which is extremely user friendly.

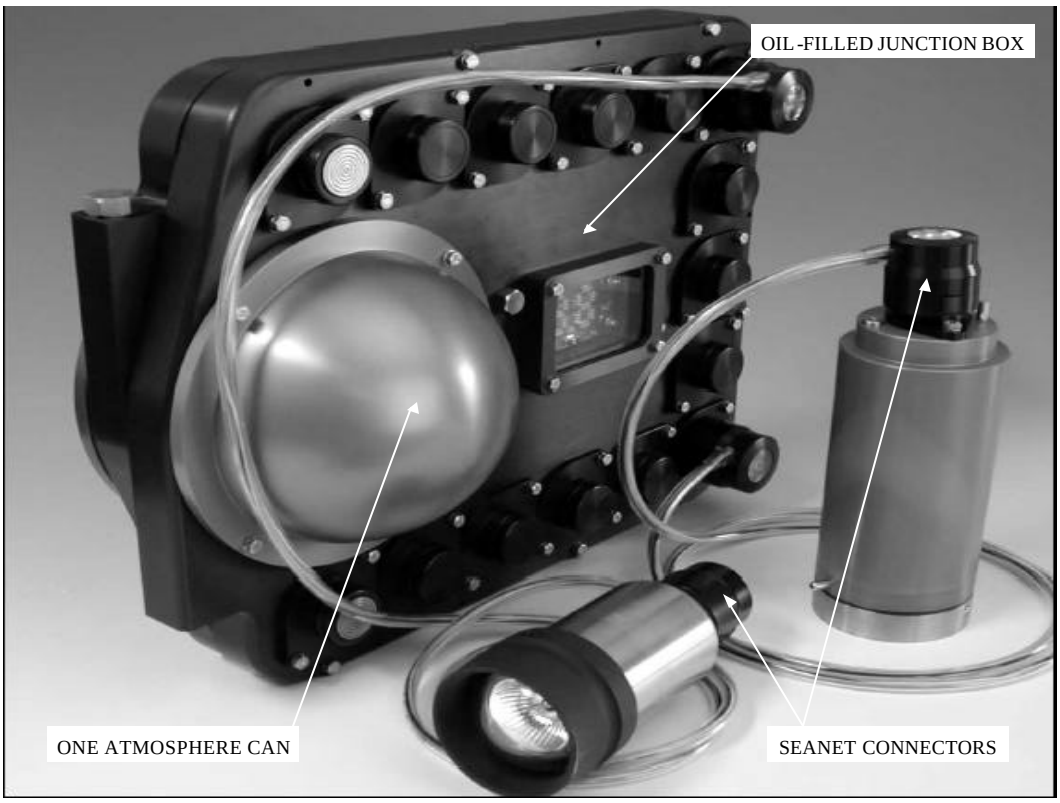


Figure 2.2: ALSTOM Schilling SeaNet Telemetry Hub[3]

The design from Schilling emphasizes modularity on the scale of a full-size ROV. Figure 2.2 shows the central control module called SeaNet. This hub has the ability to control an entire vehicle, and if extra capacity is needed, another hub may be added on. Although small in size for a control system of this capacity, it

proves cumbersome if only a few control functions need to be added. The small, one-atmosphere sphere that houses the processor, the SeaNet connectors

attached to both a camera and light, and the rectangular section of the module that serves as an oil-filled junction box can be seen in the figure.[4]

BENTHOS, INC. –

Benthos was founded in 1962 with the goal of designing and producing custom designed oceanographic research equipment.[5] The company is based out of North Falmouth, MA and is most widely known for the production of underwater acoustic systems (transponders, releases, imaging), flotation, and ROVs.

Figure 2.3: Benthos Super SeaROVER[6]

The vehicles they produce include the EROV, a small inspection ROV for the nuclear power industry, the MiniROVER Mk II, the Openframe, the Openframe MiniROVER Mk II, the SeaROVER, the Super SeaROVER (Figure 2.3) and the

Stingray (Figure 2.4). The Stingray uses a "proprietary digital control system developed by Under Control which utilizes an open system architecture based on an embedded Linux operating system."[7]

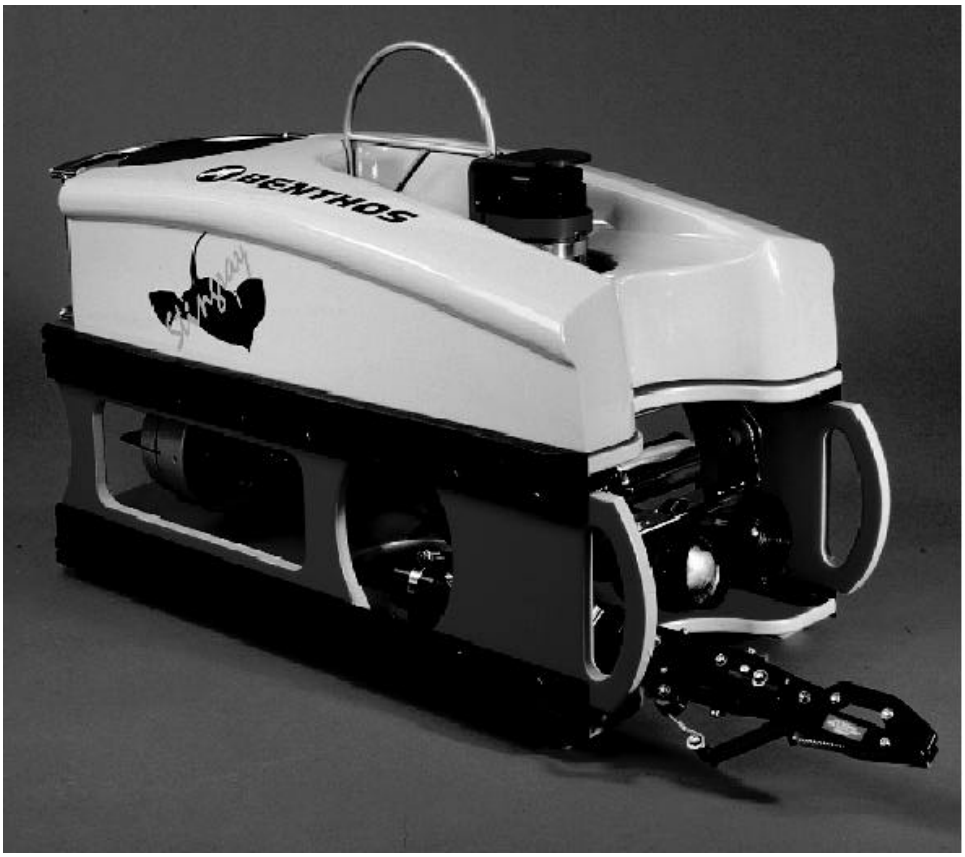


Figure 2.4: Benthos Stingray[8]

DEEP OCEAN ENGINEERING, INC. –

DOE builds the popular Phantom line of ROVs commonly used for scientific research, military applications, hull inspections, nuclear facility work, television, and police search and recovery. The company was formed in 1982 and is based in San Leandro, CA.[9]

Figure 2.5: DOE Phantom XTL[10]

The Phantom ROVs (Figure 2.5) are small, portable and based upon a common electrical architecture that allows interchangeability for spare parts and topside controllers. Very little electric hardware is located on the vehicle side allowing for a light weight product.

DEEP SEA SYSTEMS INTERNATIONAL, INC. –

DSSI manufactures the MAX-Rover line of ROVs that includes the Mk1, Mk2 (Figure 2.6), Mk3, Mini-MAX, and Omni-MAX. The company was founded

in 1983 in Cataumet, MA. Their ROVs have the ability to operate in depths of 6000m and are available in a small package to allow for easy transport. The vehicles have been used by National Geographic productions, oceanographic research institutions, and NASA.[11]

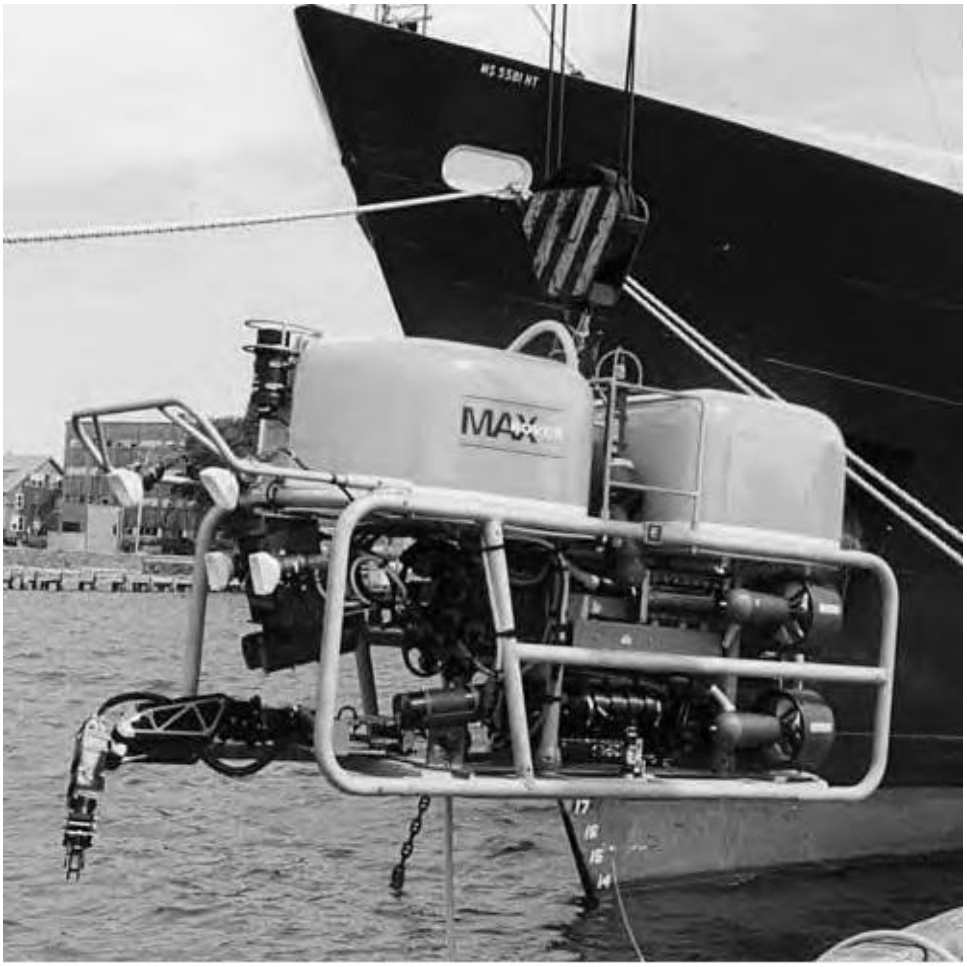


Figure 2.6: DSSI MAX-Rover Mk 2[12]

The vehicles use a "proprietary subsea Remote Data Acquisition System. The RDAS is a multi-tasking 14 bit microprocessor and supports full IEEE communications protocol, watch dog timers and multiple I/O ports."[13]

HYDROVISION/SEAEYE –

Figure 2.7: Hydrovision Diablo[14]

Hydrovision Limited was founded in 1989 and is located in Aberdeen, Scotland. They produce ROV components such as electronic and hydraulic control systems as well as ROVs. Seaeye Marine Limited was founded in 1986 and

acquired by Hydrovision in 1999. They are located in Fareham, Hampshire in southern England. The Hydrovision line of vehicles are primarily hydraulic work class types and include the Demon, Diablo (Figure 2.7), Hyball, Offshore Hyball, and Venom. Seaeye produces all electric ROVs such as the Falcon, Lynx (Figure 2.8), Panther, Puma, Surveyor Plus, and Tiger 1000.

Figure 2.8: SeaEye Lynx and TMS "Garage"[15]

Hydrovision recently introduced their CURVETECH control system based on the PC-104 footprint (Figure 2.9). Their development includes the following points[16]:

Selection of components kept to standard items available from more than one source.

Chose PC-104 and configured it to run as an Allen-Bradley PLC (programmable logic controller).

Based software programming on SCADA, OPC, DF1, and ladder logic, communication protocols and programming languages common to industrial PLCs (see glossary for definitions of these terms).

Claim to be able to run the control system on any PC-based host.

Configured system such that it can be modular from tooling packages up to full size ROV's

Figure 2.9: Hydrovision CURVETECH PC 104 Control System [17]

The CURVETECH system was developed with the main requirement that it be a "new, scaleable control system for ROVs, subsea tooling and other applications." (Hydrovision, 1998) This design requirement closely follows the goals laid out in the beginning of the chapter. The use of PLC style controllers allows for compatibility with many industrial products but these require a programmer who is fluent in the communications protocols and programming methods mentioned above. As mentioned in the introduction, one of the goals of the design in this paper is to maintain an easily expandable system. The use of the C programming language is viewed as a primary tool of achieving this requirement.

The selection of a PC-104 platform is excessive for the requirements. While the PC-104 is readily available from a variety of manufacturers, a single board system based on a microcontroller such as the DSP selected here is more efficient as far as processing power and can take up less physical space.

INTERNATIONAL SUBMARINE ENGINEERING LTD. –

ISE was founded in 1974 along with its sister company ISE Research, Ltd. They specialize in robotics for harsh environments including ROVs, specialized subsea tooling for offshore oil and gas as well as oceanographic research, robotic manipulators, and AUVs (autonomous underwater vehicles).

Figure 2.10: ISE Hysub 250[18]

Most of their large control projects are based upon the custom designed ACE (Automated Control Engine). “ACE 3.0 is a fast and powerful open architecture real time, event-driven control engine. The software allows control

systems engineers to create highly configurable soft control systems based on re-usable software components. A library of control components is included to address a broad range of configuration options. ACE can be configured as a soft PLC Control System or as a DCS (multiple instances of ACE on a network)."[19]

Unique points[20]:

Supports Windows NT, QNX, DOS, and custom apps developed for DSPs and embedded systems

Communications protocols - Modbus, ARC Net, TCP, Ethernet, UDP and Device Net

Have also developed a control system based upon PC-104 architecture for MBARI (Monterey Bay Aquarium Research Institute) (Figure 2.11).

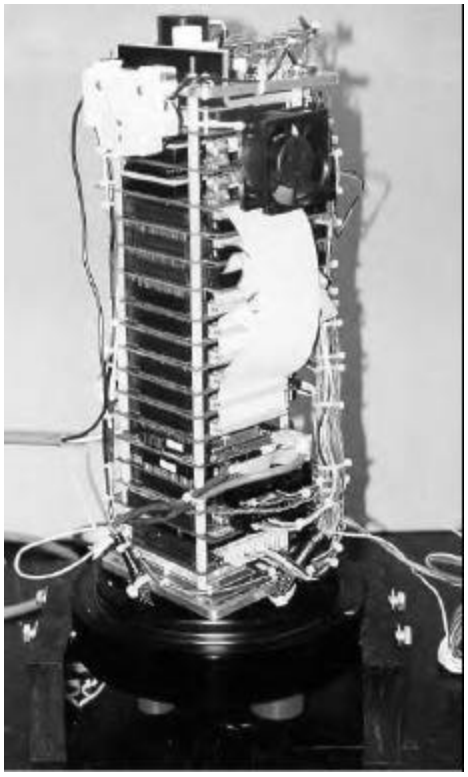


Figure 2.11: ISE PC 104 Control Pod designed for MBARI[21]

ISE has developed this proprietary control engine based upon the expansive library of code they have assembled. As a result, they can put together a control system using virtually any of the common hardware platforms and operating systems in use today.

MITSUI ENGINEERING AND SHIPBUILDING CO., LTD. –

Mitsui is a large shipbuilding company with a division that builds small inspection ROVs. They are also known as the manufacturer of the Kaiko, which is the deepest diving ROV in the world capable of reaching the bottom of the Marianas Trench (11911m). Their vehicles include the inspection ROV RTV-200 Mk II, the Dolphin 3k, and the Kaiko (Figure 2.12).

Figure 2.12: Mitsui Kaiko, 10,000m Depth Capability[22]

OCEANEERING INTERNATIONAL, INC. –

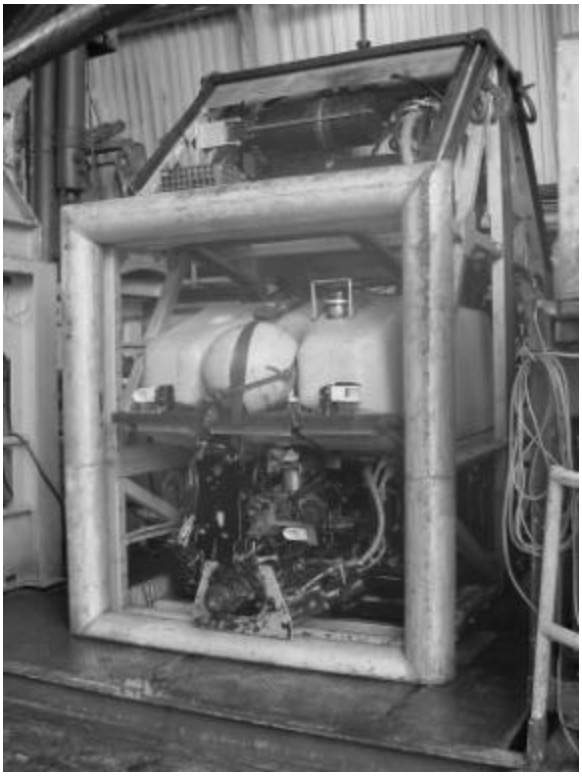


Figure 2.13: Oceaneering Hydra Magnum with Torque Tool and "Garage" TMS

Oceaneering holds a 33% market share of the worlds ROV operations. They were formed as a diving company in 1964 and are based in Houston, TX. Currently they operate over 120 systems that include the Hydra Magnum (Figure 2.13), Hydra Millennium, Hydra Minimum, Phoenix, Quantum, Mongoose and deep diving Magellan (Figure 2.14).[23]

Figure 2.14: Oceaneering Magellan (8000m) with Phoenix V in Background

A majority of the vehicles operate on a PC-based, industrial backplane, control system developed by GESPAC Industrie. The company has also produced control systems based upon the PC-104 architecture.[24]

PERRY SLINGSBY SYSTEMS –

Perry Slingsby is a Coflexip Stena Offshore group. It is the result of the 2000 merger of Perry Tritech and Slingsby Engineering. They have two main offices in York, England and Jupiter, FL. The company's customers include offshore oil and gas, telecommunications, nuclear facilities, and the military. They have built 300 ROVs and 150 diving and submarine systems since their formation 35 years ago. This comprises 50% of the world's commercial ROV fleet.[25]

Figure 2.15: Perry Slingsby Triton MRV[26]

The systems they produce include the Flexjet, Gator I and II, MRV, Olympian, Scarab III, Scorpion, Trojan, Viper, Voyager, and the Triton class vehicles (Figure 2.15). These systems operate on a PC-based, industrial backplane control system (Figures 2.16, 2.17).

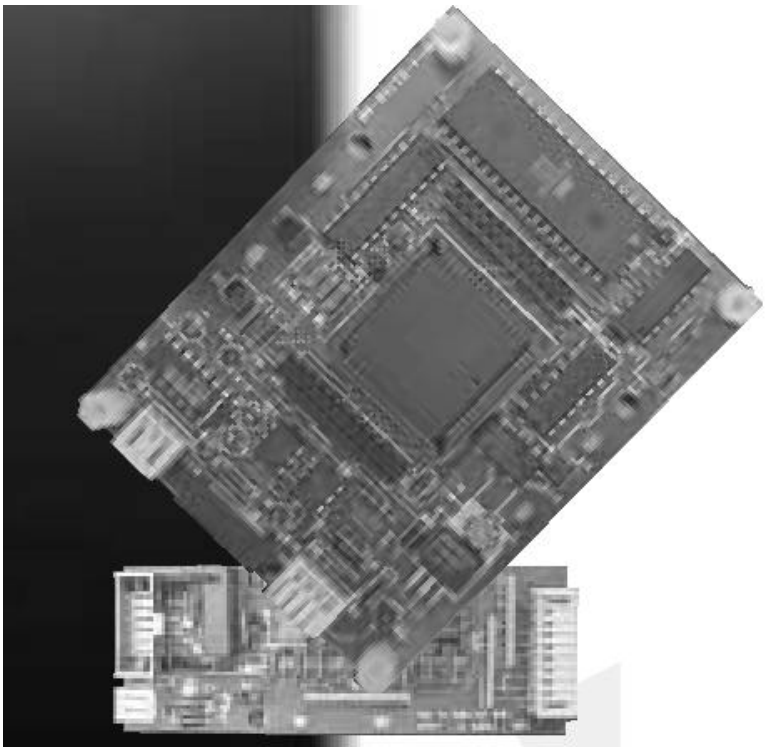


Figure 2.16: Perry Slingsby PCBs[27]

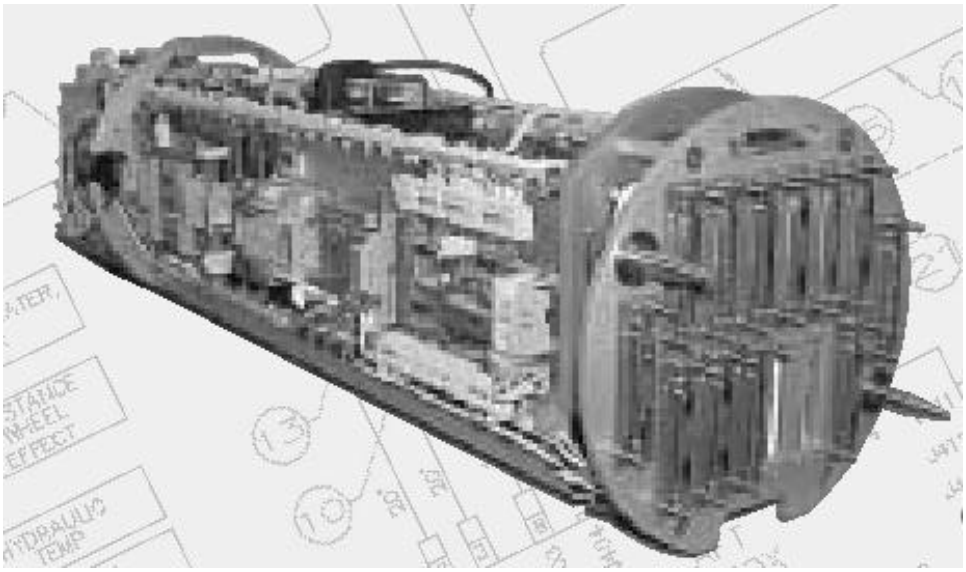


Figure 2.17: Perry Slingsby Control Pod[28]

THE SONSUB GROUP –

Sonsub is owned by Saipem SpA, a division of the Italian company ENI/AGIP. They were bought by Saipem in 1992 and are based out of Houston, TX.[29] They operate 14 ROVs and 7 cable burial/trenching systems that were designed in house, plus a number of vehicles provided by outside manufacturers. These in house designs include the Innovator ROV (Figure 2.18), the TLP Riser Inspection Vehicle, the TLP Riser in-service Inspection Vehicle, as well as the Centaur, Giano, Metra, and Sedna cable burial systems. These systems operate on a PC-based control system.

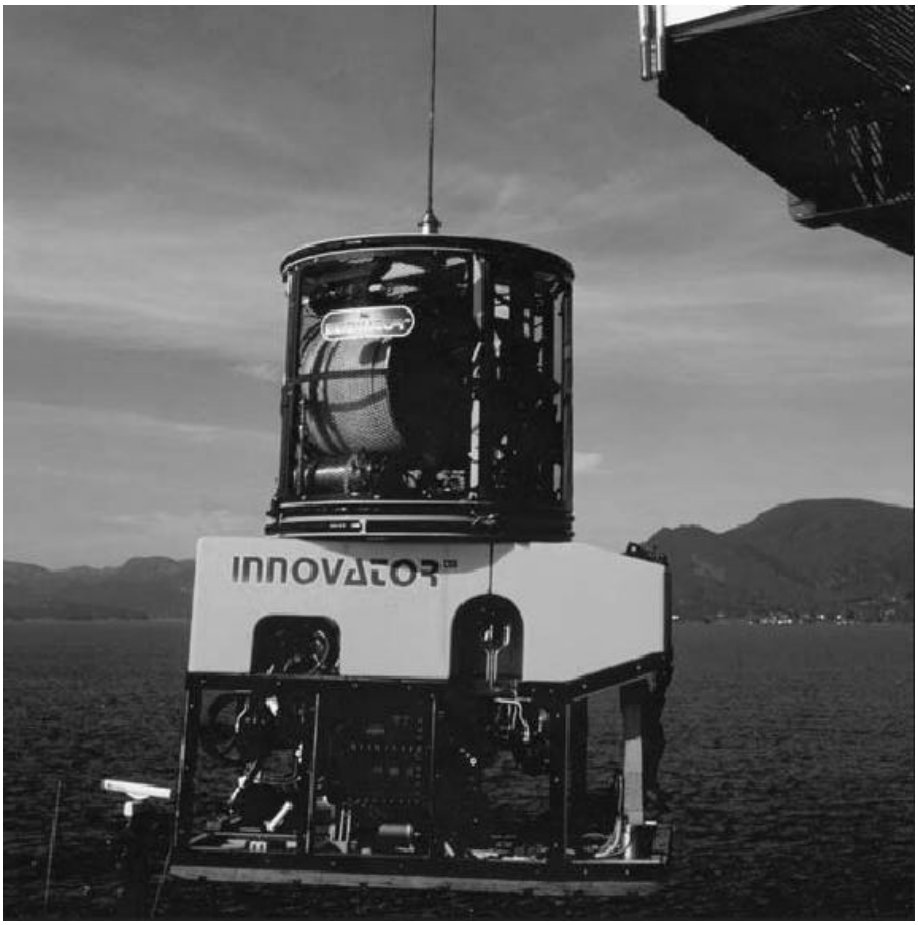


Figure 2.18: Sonsub Innovator with "Tophat" TMS[30]

STOLT OFFSHORE LTD. –

Stolt is an offshore construction company with locations in Stavanger, Norway, Aberdeen, Scotland, and Houston, TX. They operate a fleet of 90 ROVs including over 20 that were designed and built in house.[31] These 20 Stolt Core Vehicles (SCVs) include the SCV Solo Mk 2, the 100, the 1500, and the 3000 (Figure 2.19). They use a PC-based control system along with the ARCNet communication protocol.

Figure 2.19: Stolt Core Vehicle (SCV) 3000 with A-Frame Launching and Recovery System[32]

SUB-ATLANTIC LTD. –

Figure 2.20: Sub-Atlantic Super Mohawk with Composite Frame[33]

Sub-Atlantic is an ROV and specialty, subsea tooling manufacturer located in Aberdeen, Scotland. They produce fully electric observation and small, work-class vehicles including the Apache, Cherokee, Mohawk, and Super Mohawk (Figure 2.20). Their telemetry system (the SUB-0176) is based on the VersaModular Eurocard or VME bus (see glossary). This includes the standard Eurocard and a non standard octagonal shaped card (Figure 2.21).

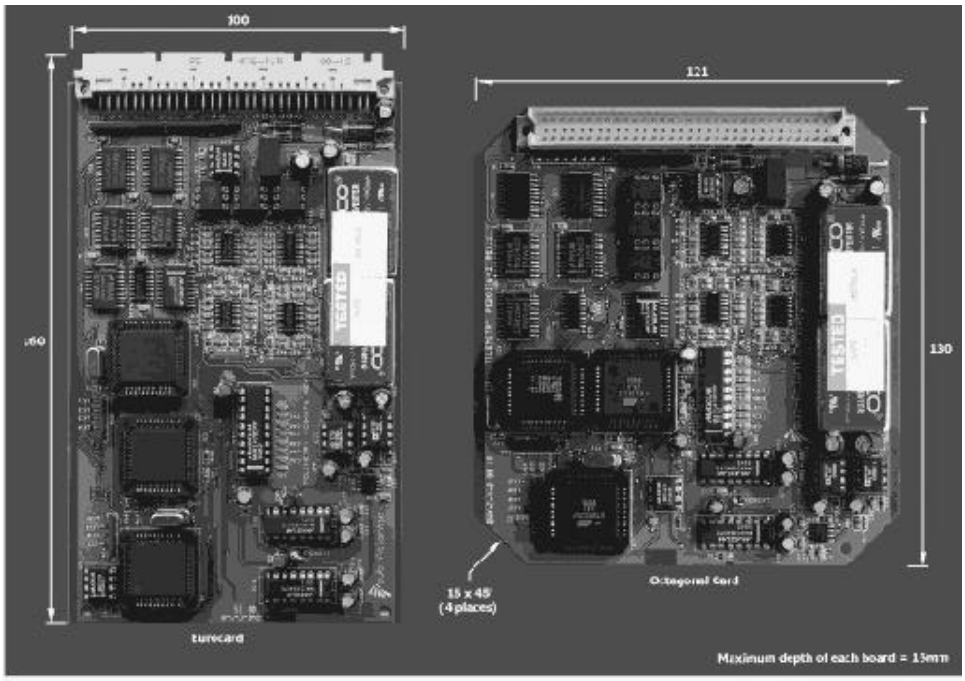


Figure 2.21: Sub-Atlantic PCBs – Eurocard and Octagonal[34]

SUBSEA 7 –

Subsea 7 is the result of the combination of Halliburton Subsea and DSND Subsea in 2002. They operate a fleet of 112 ROVs with a maximum water depth capability of 5000m.[35] The vehicles include the Tuna, Centurion (Figure 2.22), Clansman, Eagle Eye, Examiner, Hammerhead, Hercules, Pioneer, Stealth, and Warrior along with vehicles manufactured by Perry Slingsby and Hydrovision. Varying control systems are used in their many systems. The Tuna uses three programmable logic controllers (PLCs), two on the vehicle and one topside. The Warrior and Hercules use a PC-based system using multiple printed circuit boards (PCBs) connected on a parallel bus.

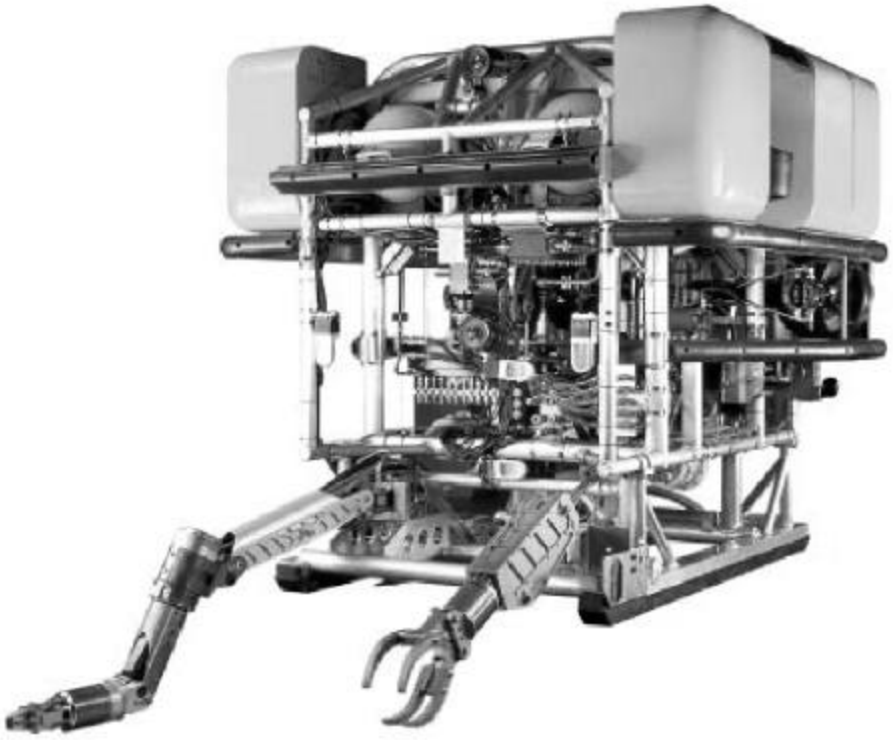


Figure 2.22: Subsea 7 Centurion[36]

THALES GEOSOLUTIONS –

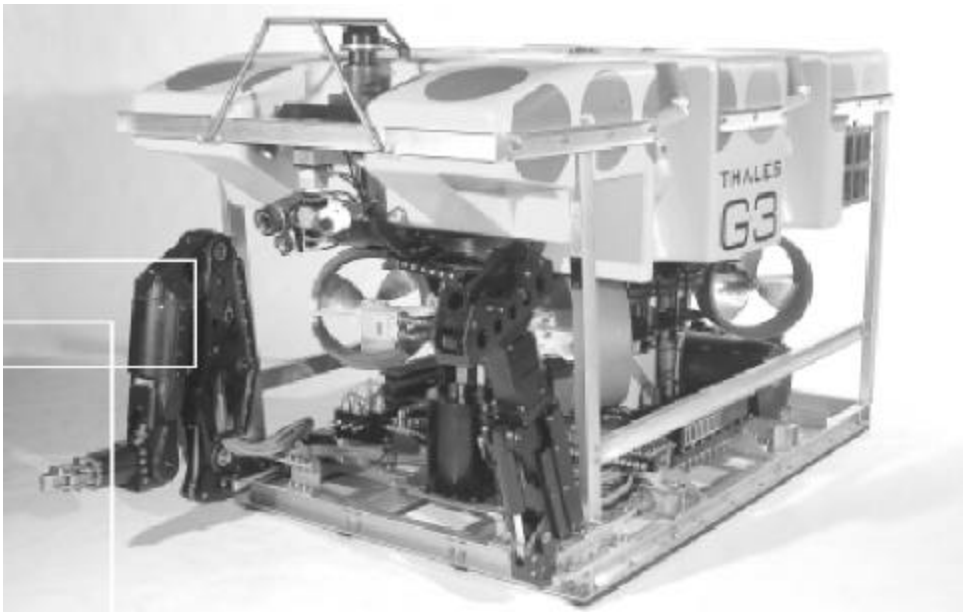


Figure 2.23: Thales G3[37]

Thales GeoSolutions is based in London and is owned by the French company Thales Electronics Plc. Their business concentrates on GPS positioning and tracking, ROV design, and geo-technical sensor development. They operate a fleet of approximately 50 ROVs including the Sea Pup, G3 (Figure 2.23), Seal, Sealion Mk II (Figure 2.24), Sealion 3000, and Sea Serpent. The Seal and Sealion Mk II use a control system based upon the Zilog Z80 family of microcontrollers.[38] The more recent vehicles use a PC-based rack system using the ARCNet protocol.[39]

Figure 2.24: Thales Sealion Mk II[40]

Offshore Control Industry:

ABB –

ABB develops automation systems for industrial and utility use. They focus on large system developments that can be integrated throughout a customer's company including engineering, purchasing, management, etc. The company's Oil, Gas, and Petrochemicals group develops control systems for production, work-over, and process equipment (Figure 2.25). These subsea control systems are developed around open architecture communication protocols such as HART, Foundation Fieldbus, and PROFIBUS (see Glossary for definitions). These types of protocols are ideal for industrial applications and harsh environment areas such as below the ocean surface. The protocols themselves are designed to be usable in high noise environments with built in error checking. Since it is an open architecture, the designer is allowed flexibility in the size and expandability of the

system as well as the peripheral equipment that can be used. However, the downside of all this design flexibility is a relatively expensive and complicated system to install. For large process automation control systems such as a chemical plant or a subsea drilling control system, this approach is probably more sensible. For the small, baseline control system described in this writing, it is a bit more complicated than the project requires.[41]

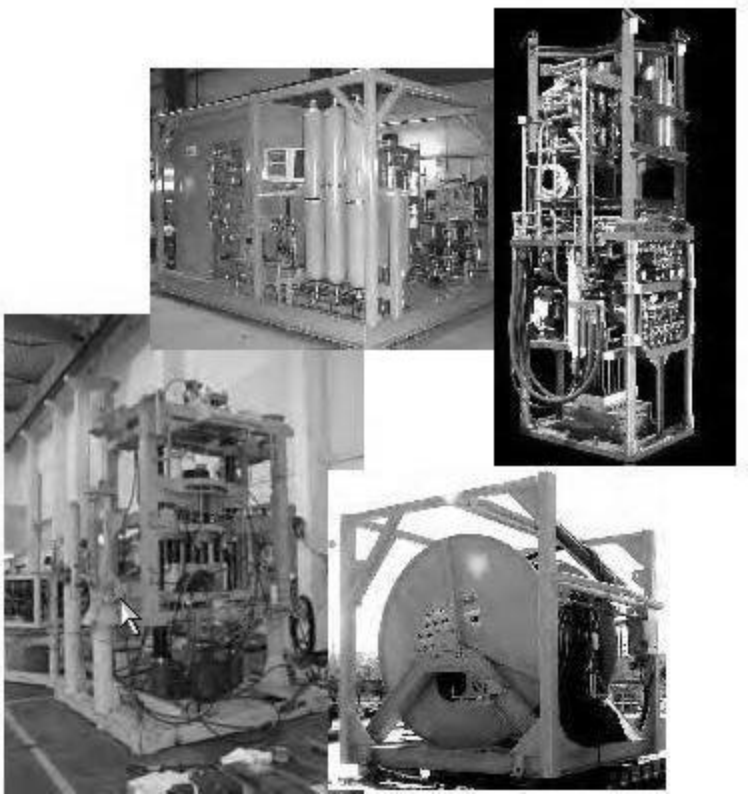


Figure 2.25: ABB (Clockwise from top left) Workover Control Package, Deepwater Control Pod, Control Umbilical Reel, Subsea Running Tool[42]

Government and Educational Research Programs:

FLORIDA ATLANTIC UNIVERSITY –

The Autonomous Underwater Vehicle (AUV) department of FAU has developed a number of vehicles over the past decade including the Ocean Voyager I and II, (Figure 2.26) and the Explorer series. The development of an AUV has different requirements from an ROV design. An AUV must have all processing power onboard the vehicle. There are no topside computers or operators to share decision making tasks. This means that the selected control system must have the processing power and speed to perform navigational duties as well as mission specific tasks simultaneously. This being said, it is still educational to review AUV control systems and explore any similarities with their ROV brethren.

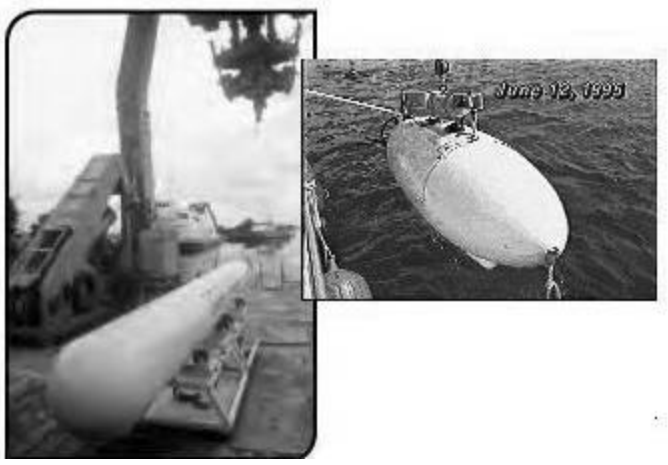


Figure 2.26: FAU Ocean Voyager I and II[43]

One of the goals of their designs at FAU was to provide a modular system with mission specific work packages. (FAU) To accomplish this goal, the LON Works network protocol was selected. This control system is similar to a CAN

system in that it de-centralizes control to a network of multiple nodes communicating via a common bus.

The university has also used the real time operating system VxWorks from WindRiver combined with control modules written in C to produce the Ocean Voyager's Intelligent Control System (ICS). The system uses the VME bus with two onboard 16 MHz 68020 processor.[44]

Harbor Branch Oceanographic Institution –

HBOI, located in Ft. Pierce, FL, is a research and educational institution that has been designing and building ROVs since the CORD (Cable Operated Remote Device) in 1973. Their vehicles have included the CORD, the SCOOP (Scientific Collection and Observation Platform), the Life Guard Panther (Figure 2.27), and the HBOI Fly Away, a deep water version of the Deep Sea Systems Mini Rover. They develop PC-based control systems and were a consultant on the MBARI (Monterey Bay Aquarium Research Institute) Ventana ROV.[45]

Figure 2.27: HBOI Life Guard Panther Deployed with "Tophat" TMS[46]

IFREMER –

Ifremer, or the French Research Institute for the Exploration of the Seas, is a public research institute controlled by the four French ministries of Research, Agriculture and Fisheries, Transport and Housing, and Environment. They operate the Victor 6000 ROV (Figure 2.28) which they developed in conjunction with the French company ECA. ECA specializes in control systems developed around parallel architectures and CORBA (Common Object Request Broker Architecture).[47]

Figure 2.28: Ifremer Victor 6000 with Under-Vehicle Work Skid[48]

JAPAN MARINE SCIENCES AND TECHNOLOGY CENTER –

JAMSTEC was created in 1971 and is located in Yokosuka City, Japan. The Deep Sea Research Department operates two manned submersibles as well as four ROVs. The Kaiko and Dolphin-3K (Figure 2.29) were manufactured by Mitsui, while the UROV7K and the Hyper-Doplhin were manufactured in house with consultation from Mitsui.[49]

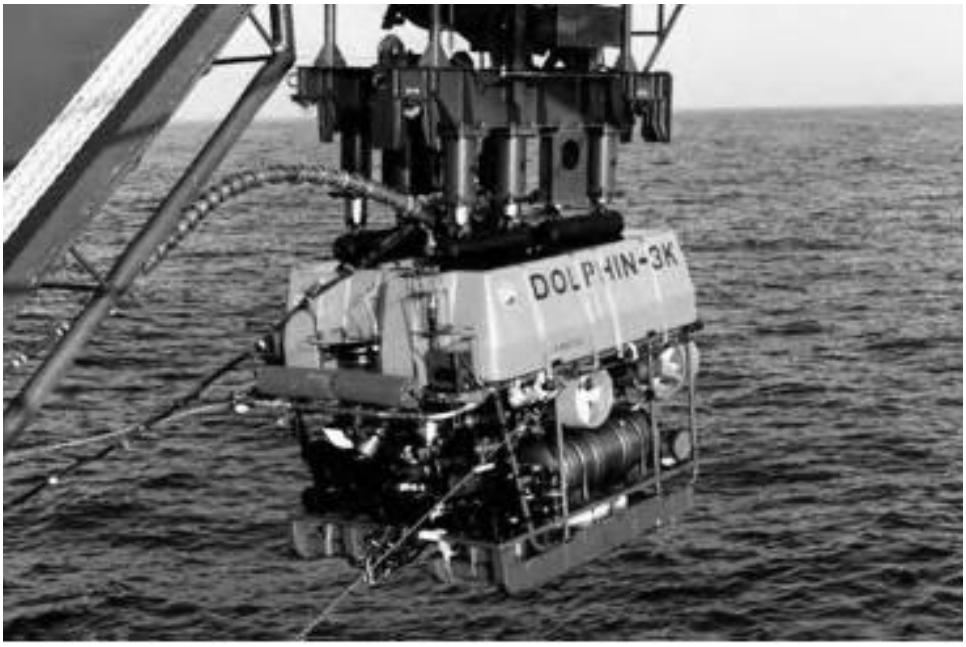


Figure 2.29: JAMSTEC Dolphin-3K with A-Frame LARS[50]

MONTEREY BAY AQUARIUM RESEARCH INSTITUTE –

MBARI is an educational and research institute located in Moss Landing, CA. They operate the ROV Tiburon (Figure 2.30) which was designed in house with outside consultation and equipment provided by ISE, HBOI, and WHOI (Woods Hole Oceanographic Institute). The Tiburon control system is based on the VME (VersaModular Eurocard) bus and uses the Intel 87C196KC chip as its main processor. MBARI produced nine custom PCBs (printed circuit boards) to meet

project specific goals. These "D" shaped boards were produced to incorporate an 8 bit backplane bus and fit inside a 6" inside diameter housing.[51]

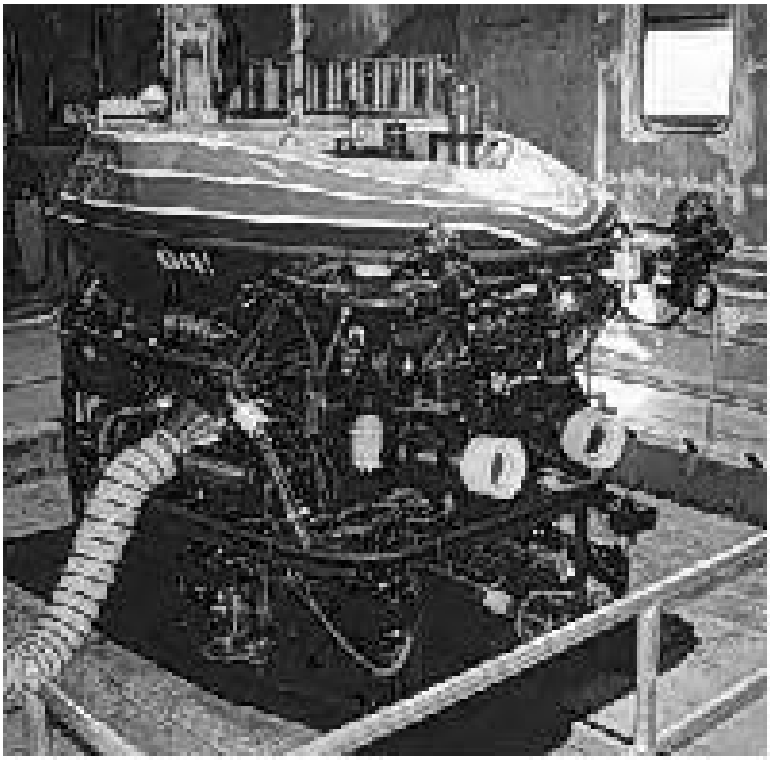


Figure 2.30: MBARI Tiburon[52]

WOODS HOLE OCEANOGRAPHIC INSTITUTE –

WHOI is a research and educational institute located in Woods Hole, MA. Most widely known for the manned submersible ALVIN, they also operate the ROV combination Jason II/ Medea (Figure 2.31). These vehicles function in tandem with Medea also acting as a suppressor weight to uncouple Jason from surface motion conveyed along the main lift umbilical. Ethernet is the communication protocol used onboard.[53]

Figure 2.31: WHOI Jason II/Medea[54]

Results:

As the examples above show, a number of companies have developed modular or expandable control systems in the subsea industry. However, the goals or design decisions of these existing projects resulted in a product that does not meet the requirements of this thesis. Schilling has developed a unique system based upon PIC microcontrollers however; the scale of the design is much too large to consider using for something as simple as an ROV torque tool. Hydrovision has developed a basic control module for tooling and ROVs based on the PC-104 platform. Although widely available and contained in a small footprint, the PC-104 provides more processing power than necessary and is still relatively large when compared to the SBCs (single board computers) developed with microcontrollers. As will be seen in chapter 5, a single board containing the DSP microcontroller and all I/O connections, along with all necessary hydraulic components can be

incorporated into one single, small package. This would not be possible with a PC 104 stack.

The result of this research into existing systems gave insight into how the subsea industry has approached control system development. It has shown that no company has developed a simple control system and then followed through by using this baseline system (and the experience gained from its development) in a more complex project. To answer the questions mentioned at the beginning of the chapter, yes there are similar systems out there. However, no one has tried to incorporate all the concepts described in this thesis into one single design which makes this research unique. These ideas include:

A basic control module that can be chained together in multiples to control more complex systems.

The use of microcontrollers to create a small, single board controller.

The selection of the CAN (Control Area Network) communications protocol that allows for the expansion of the system.

Chapter 3
Microcontroller Selection Process

An ROV control system is comprised of a topside or surface control unit and a bottom side or vehicle unit connected by an umbilical that carries power and data signals. The purpose of the topside unit is to provide a user interface for the operator as well as perform a majority of the processing tasks. This portion of the control system receives operator inputs through hardware such as joysticks, mice, sliders, and pushbuttons. It also provides status information on vehicle systems through a graphical user interface (GUI) which is typically seen as an overlay on a video monitor. The vehicle control unit receives commands from the topside unit and relays these commands to individual subsystems to carry out the required task. This control unit must also be able to collect sensor and status information that is relayed back to the topside control unit.

A good number of existing ROVs use PC based control systems on the vehicle side. While these provide a robust and relatively easy to program platform, they are not necessarily suited to the task. Bus protocols such as VME and ISA (PC 104, for example, uses a modified ISA protocol) typically consist of a number of PC boards connected via a back plane bus. One card is dedicated to the processor, another to digital I/O, another to analog I/O, and so on. All this hardware must be contained in a large sealed housing (see Figure 3.1) with multiple connectors to attach to the ROV subsystems. With the use of a microcontroller, the processing and I/O capabilities can be found on the same microchip. This in turn can be used to create a single board computer (SBC) requiring less space, substantial weight savings, and a reduction in vehicle wiring.

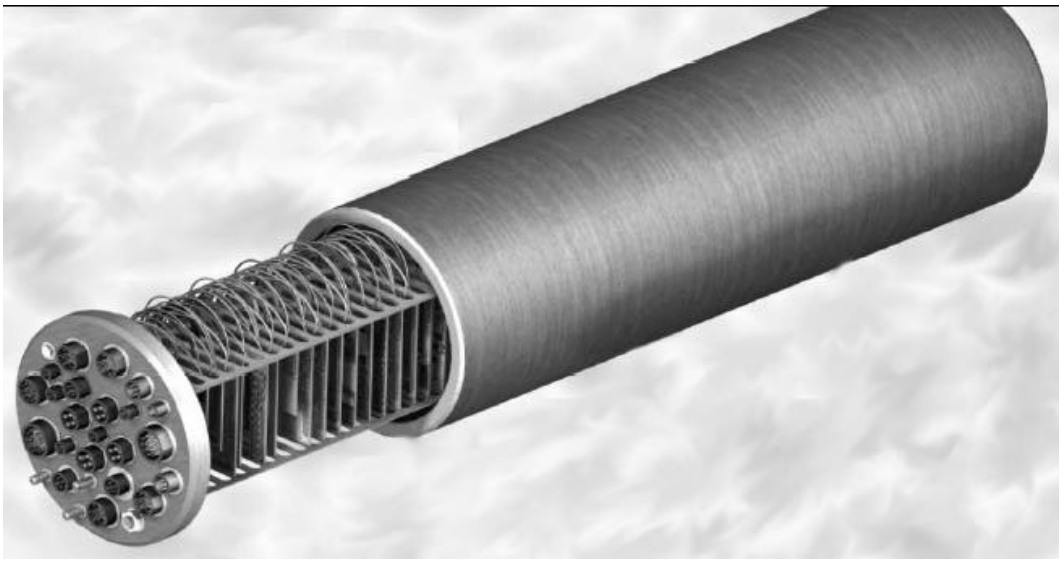


Figure 3.1: Typical ROV Control Pod[1]

The microcontroller selection process for this control system revolved around a list of requirements for the most basic application (in this case a subsea torque tool) and the ability to expand modularly to accommodate more complex systems. The final selection was also limited by time and money constraints. The first section of this chapter will outline the basic tasks this control system must be able to accomplish. The second section explains the choice of the Control Area Network (CAN) to meet the expansion requirements. The final section describes why the Motorola DSP56F805 was selected and how it meets the design requirements.

Baseline System:

The first question to be answered in order to define the basic requirements is: What is a "smart" ROV torque tool or rotary actuator intervention tool? According to API SPEC 17D, a torque tool applies "torque to a rod or other linkage to operate a valve, connecting device, or other rotationally operated subsea well

equipment apparatus."[2] Subsea oil field equipment such as christmas trees and blow out preventers (see glossary) contain valves that require ROV intervention during installation, work-over (repair, upgrade, or scheduled maintenance), and sometimes during time of emergency (failure of surface control system). These valves have what are called end-effectors or rotary actuator fixtures attached to the valve stems that allow an ROV operable torque tool to either close or open the valve by rotating the stem. As a result of the misuse and lack of control of these tools, expensive equipment has been damaged resulting in the loss of a great deal of money. Thus the development of the "smart" torque tool, which implies the tool has an electronic control system with feedback information such as torque, hydraulic feed pressure, hydraulic flow, and turns count. The control system gives the operator the ability to proportionally control the speed the tool rotates at and the torque it can produce.

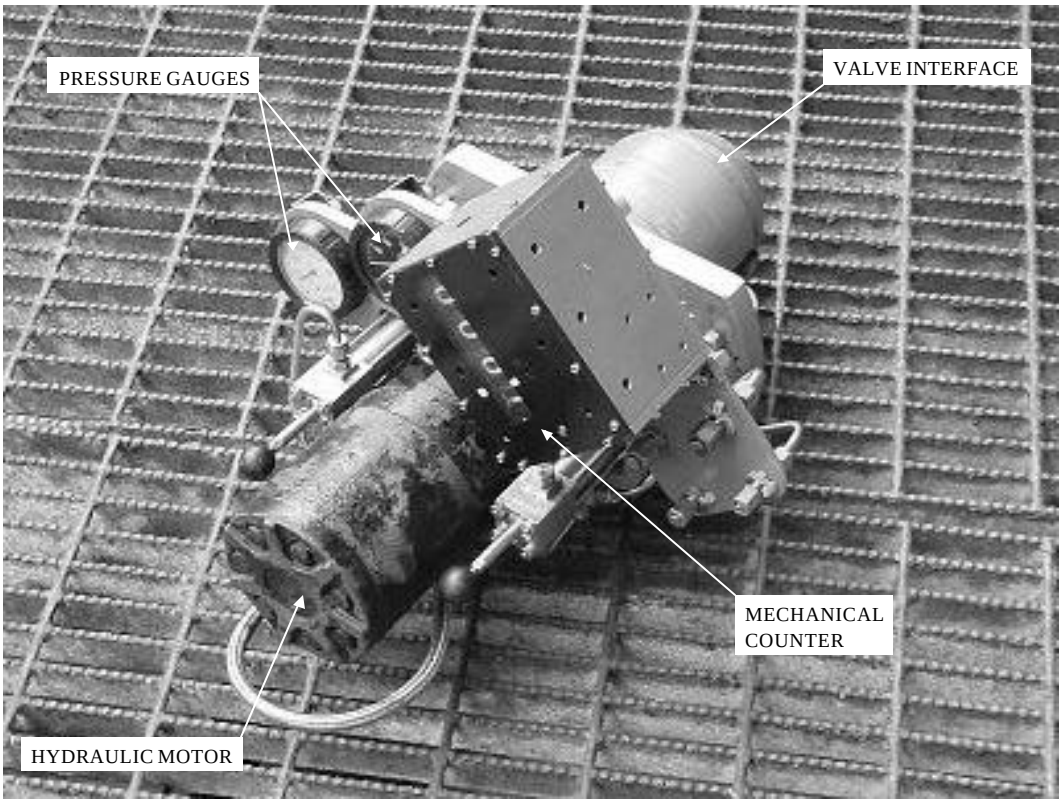


Figure 3.2: ROV Operable Torque Tool with Mechanical Counter

The basic, mechanical torque tool without electronic controls is seen in Figure 3.2. It consists of a hydraulic motor in line with the valve interface or socket. Two pressure gauges display the pressure on the "A" side or "B" side depending on which way the tool is turning. A mechanical counter with chain drive displays the turns count. The typical method of using the tool is to calibrate it on deck using a torque tool test jig (Figure 3.3) and record pressure versus torque. A hydraulic pressure relief valve is set on the surface to limit the maximum torque. Hydraulic flow is adjusted with a hand operated needle valve to control speed.

The current "smart" tools have a telemetry link to the surface that transmits the pressure and flow data. Torque readings (measured via a series of strain gages) and turns count (recorded using a number of magnets and a reed switch or Hall Effect sensor) are also relayed to the surface. The control system incorporates

proportional pressure and flow control valves that allow the operator to adjust the speed and torque during the dive via the GUI. This allows the tool to be used for multiple jobs requiring different torques and rotational speeds. The proportional adjustment also allows the rotational speed to be ramped up to prevent shock loading. The selection of the microcontroller and associated demonstration board had to supply the following capabilities:

Turns count information displayed either via an LED or transmitted to the surface.

Turns counter (Hall Effect or reed switch) input – digital I/O.

Torque (strain gage) input – analog I/O.

Communication link for relay of information such as pressure and flow.

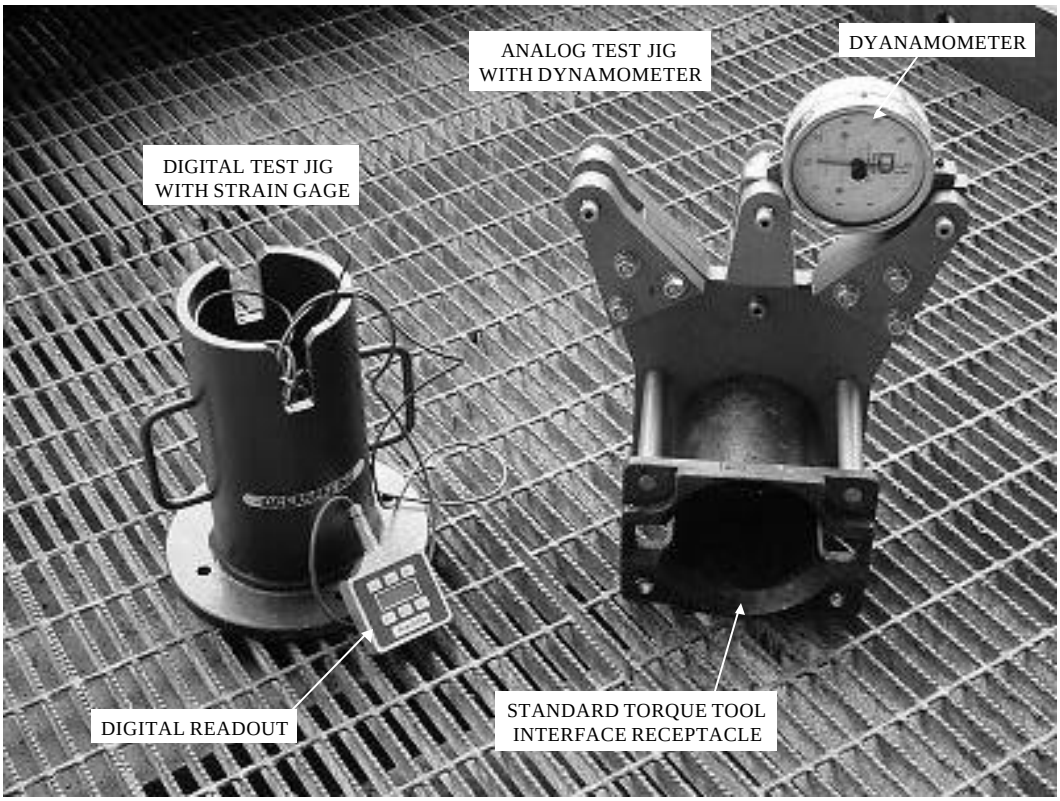


Figure 3.3: Torque Tool Test Jigs

Beyond these initial requirements, a valve pack with proportional controlled flow and pressure valves is supplied with this product. These valves require a variable analog input for control. In order to complete the system, the controller would also have to be able to drive a digital to analog converter (DAC). The entire baseline list consists of the following:

Digital I/O port capable of receiving up to eight (8) separate sensors.

Analog to digital (ADC) port capable of receiving (4) separate signals.

Digital to analog converter capable of driving three (3) signals.

One (1) serial communication port, RS-232 0r RS-485 compatible.

Method of Expansion:

The torque tool control system designed for this thesis requires a method for expansion to develop more complex control systems such as for a work-class ROV. A communication method had to be selected to provide for data and control signals to move between the various subsystems of the ROV. The following communication protocols were investigated for this purpose.

UNIVERSAL SERIAL BUS –

"Plug and play" was first pursued as the easiest way to create an expandable system, which led to researching the PC bus known for this attribute, the universal serial bus (USB). USB allows the user to "hot" plug an item onto the bus and the software handles the integration. "Hot" plug means that the item can be plugged into the system without a power down or reboot. The device then transmits an identifier which tells the host computer what the device is and what software drivers need to be loaded. If the item is not recognized or drivers are not available, the user will be prompted to provide the information and/or files. An added benefit is that low power items (5 volts or less) can be powered via the bus.[3]

These basic principles seem like an excellent idea upon which to base the expansion of an ROV. The bus supplied power would simplify wiring. Although the "hot" plug option is interesting, in the offshore world this is not typically done due to safety and money issues due to the remote chance that a piece of equipment could short circuit when connected. The problem with this bus, though, is that it was not developed for the industrial environment. Maximum transmit length is approximately 9 meters over standard USB cables and problems will arise in high noise environments. An ROV with motors running off of upwards of 3000 volts, hydraulic pumps running, and other equipment, qualifies as a high noise environment.

TCP/IP –

The data transfer protocol TCP/IP (Transmission Control Protocol/Internet Protocol) was investigated because of its popular use in local and wide area networks (LANs and WANs) as well as being the standard communication protocol for the Internet. The TCP/IP protocol was developed to enable communication between dissimilar computer platforms without a direct connection.[4] Communication is done point to point meaning data is addressed between individual computers. This data is broken down into packets that are transmitted separately node by node or hub by hub over the network. If a node receives a transmission and it does not recognize the address, it passes the information along to the next node. Once the address is recognized by the intended receiver and all packets have been received, the message is reassembled.

This protocol is useful over large networks such as the Internet. Multiple path delivery allows for packets from the same message to arrive at the destination via different routes depending on bus congestion. For long distance transmissions, the transmitting computer does not need to wait for the message to travel the entire distance. Instead, the data takes multiple short hops from hub to hub.

ETHERNET –

The Ethernet protocol was originally developed by Xerox, Digital Equipment Corporation (DEC), and Intel in 1980. It is the most common communication specification used in Local Area Networks (LANs).[5] Ethernet has a number of standards that specify the hardware it is transmitted with as well as the maximum transmit speed. The most common is called 10BaseT where 10 refers to the bus speed (10 Mbps), and T refers to the transmission medium (twisted pair).[6]

All nodes on an Ethernet system are identified by a unique address. Bus communication can be done via unicast (single node addressing), multicast (group

addressing), or broadcast mode (all nodes addressed). 10BaseT uses a bus configuration called a "star" where all nodes communicate through common hub computers. This differs from the linear bus configuration used by 10Base2 and 10Base5 systems. A linear system defines a common line that all nodes attach to individually.[7]

Communication on the common bus is governed by the Carrier Sense Multiple Access\Collision Detection Method (CSMA\CD). When a node detects that the bus is idle for a specified amount of time it will attempt to transmit. Another node could possibly begin transmitting at the same time. If this occurs, a collision is signaled on the bus. A collision results in all nodes waiting for a "backoff" period of time before they attempt to re-send. Priority can be assigned to nodes by varying the initial time period a node waits to transmit on an idle bus and by assigning varying "backoff" times.[8]

CONTROL AREA NETWORK (CAN) –

Industrial bus protocols are designed to work in high noise environments with a high level of reliability. This means they have multiple methods of error checking designed into the protocol to provide a robust communication system. There are a number of these protocols out there such as ARCNet, Foundation FieldBus, HART, and Profibus. However, most of these systems are based upon open protocols that require proprietary software to make a complete system. The Control Area Network (CAN) developed by Bosch is an industrial bus developed for the automotive industry. The protocol is widely available on microcontrollers and PC based systems. The high level software such as CANOpen, MSCAN, and CANKingdom necessary to integrate the protocol into a control system is available from a number of sources. The CAN bus was designed to have the following attributes[9]:

Multiple layers of error checking to ensure proper communication.

Built in message prioritization which can be user modified.

The ability to drop out any node which fails error checks a user controllable number of times.

A decentralized method of networking that transmits all messages to all nodes and allows each individual component to decide whether to ignore or respond to the message.

The ability to drop a node out is particularly useful for ROV systems. If a part of the system becomes disabled (flooded with seawater, for instance) the entire vehicle may still operate and be recovered to the surface for repair.

The final selection of CAN as the best choice resulted from a few key factors. First of all, as will be seen in the next section, CAN has been integrated on a number of microcontrollers available as "off the shelf" technology. Also, although most industrial bus protocols advertise low development prices, CAN was cheapest in both initial money to be spent ($5000 for Motorola's MSCAN) and time to be invested learning the programming techniques. The determination that the time spent would be less was not realized until after initial development phase. Chapter 8 will present an overview of the CAN protocol. This chapter will describe individual attributes of CAN and compare them with other networking protocols to help explain why this was the correct choice for an ROV control system.

Controller Selection:

A number of microcontrollers on the market meet the basic requirements of the system. Processors such as Rabbit 2000 (Rabbit semiconductor), Jackrabbit (Z-World), even BASIC stamps and PIC chips (MICROCHIP) have the I/O capabilities and can be set up for serial communication. The limiting factor turned out to be the ability to deal with CAN messages. The search for this type of controller uncovered a great number of chips that were developed for individual companies in the automotive industry and therefore, proprietary information. Even if there was a way to get access to one of these controllers, that would defeat the purpose of using a product that was readily available in decent numbers. Two controllers were available through common suppliers (Digi-Key and Allied Electronics). These were the Intel 87C196CA and the Motorola family DSP56F8XX. The Motorola DSP56F805 was chosen for this project.

The Motorola demonstration board was on the shelf and ready to be shipped, but it had other benefits as well. First of all, a development environment was supplied with the board called CodeWarrior IDE (Integrated Development Environment). This provides the developer with a programming environment including a C compiler and builder as well as the capability to program the microcontroller via a parallel port connection with real time debugging. A note on the programming language: the CodeWarrior software allows programming in the C language instead of the standard Assembly. This makes the controller more accessible because of the wide spread usage of the C language.

The other software supplied with demonstration board was the Embedded Software Development Kit (SDK). This was a compilation of libraries, example code, and programming lessons which allow the developer to speed up time to production. The examples and teaching methods emphasized code which would be portable across a number of Motorola products. The code written for this thesis can

theoretically be taken directly to another chip within the DSP56F8XX family. Also, Motorola produces the M68HC12 and HCS12 families of microcontrollers that support CAN. The code is purported to be portable to these with slight modifications. Considering Motorola is consistent with their use of the SDK libraries and the CodeWarrior IDE, it is reasonable to believe the code will work with different driver subroutines.[10]

Overall, as will be seen in the following sections, the selection of the DSP56F805 was a proper choice for this task. The chip not only exceeded the basic requirements, but the SDK was an indispensable tool in meeting deadlines and speeding time of delivery. For a basic tool, such as the torque tool, the controllers from the other two Motorola families might be more suited. It should be noted that the 80 MHz bus speed of the DSP[11] is almost 10 times that of alternative microcontrollers and enables quicker response and communication times. Because of this difference in processing speed, even the simple baseline control system might experience lag times with slower chips that would be unacceptable. For the purpose of demonstrating the basic application plus the overall concept of expansion, the DSP56F805 was the proper choice.

Chapter 4
Initial Development

One of the design goals mentioned in the Introduction was to produce a software structure that is easy to understand and logical in construction. The baseline requirements outlined in the last chapter are:

Turns count information displayed either via an LED or transmitted to the surface.

Turns counter (Hall Effect or reed switch) input – digital I/O.

Torque (strain gage) input – analog I/O.

Communication link for relay of information such as pressure and flow.

It seemed a logical step to approach these design requirements individually. This would aid in the learning of the programming techniques particular to the Motorola DSP microcontroller by solving small problems one step at a time. It also encourages the production of C code that is modular in construction. Each of the programs listed below eventually helped produce generic subroutines that were used in the final baseline system. As mentioned in Chapter 1, many components of an ROV have identical functionality from a processing perspective. A subroutine written for an analog flow meter can also be used for an analog pressure transducer.

The following programs were written during initial development and will be detailed in this chapter:

"TryGPIO" – controlled the on/off status of an LED with the input from a Hall Effect Sensor; this required the use of digital inputs and outputs.

"TryREADOUT" – outputs a number to an LED readout; requires digital output.

"Serial test" – demonstrates serial communication with a laptop; requires use of the serial port.

"LabViewGPIO" – displays an incremented count read from a Hall Effect sensor on a GUI (graphical user interface) written in LabView; requires digital input, digital output, serial communications.

"adctest2" – displays the output of a variable resistor (pot) on a LabView GUI; requires analog input and serial communication.

"TryDAC" – sets the value of an analog output pin according to a user supplied value; requires analog output.

Project "TryGPIO":

This simple project had the main goal of being able to hook up an on/off switch (such as a reed switch or Hall Effects sensor) to the controller and trigger an interrupt. The code for "main.c" and "appconfig.h" can be found in Appendix A. The digital I/O ports and individual pins are configured in the subroutine main. Port B, pin 0 is set up to drive an onboard LED. Port D, pin 1 is set up to trigger an interrupt when pulled high. Upon reception of an interrupt, the program jumps to subroutine "ButtonA_ISR", which toggles the LED either on or off and resets the interrupt. One thing to note in the "appconfig.h" file is that the interrupt priority of port D had to be defined. Whereas most priorities are given a default interrupt in the related "include" file, general purpose I/O's must be defined individually. The Hall Effect Sensor used to test this project can be seen in Figure 4.1.

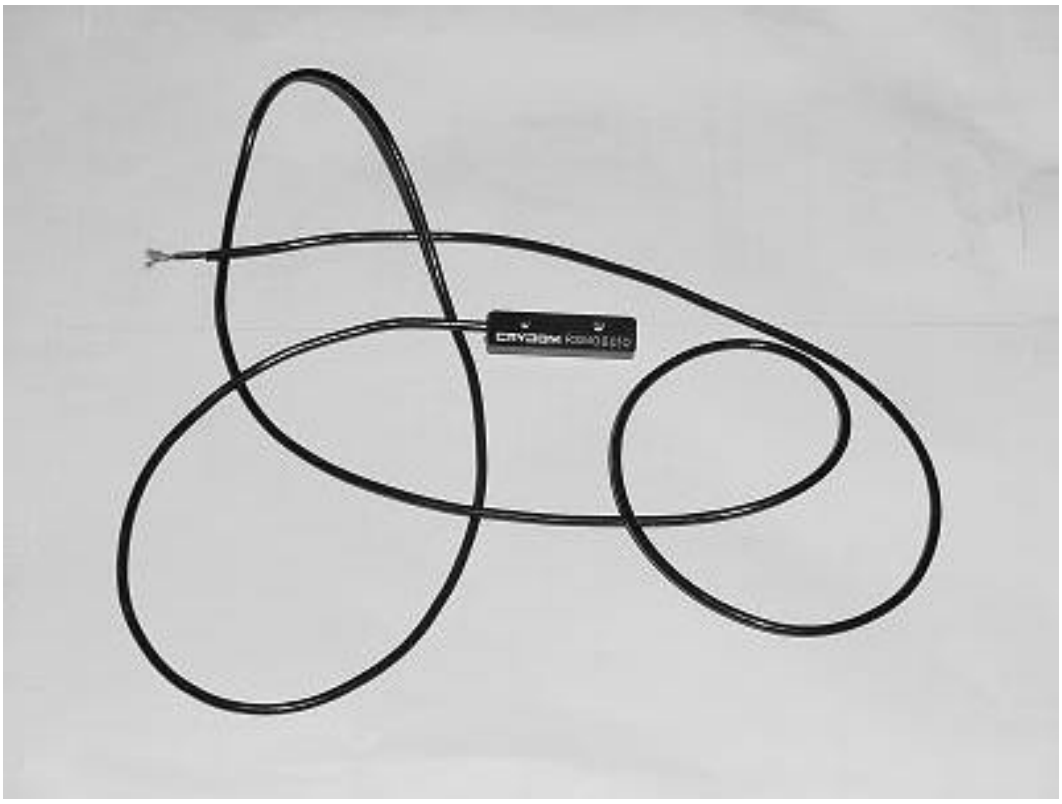


Figure 4.1: Hall Effect Sensor

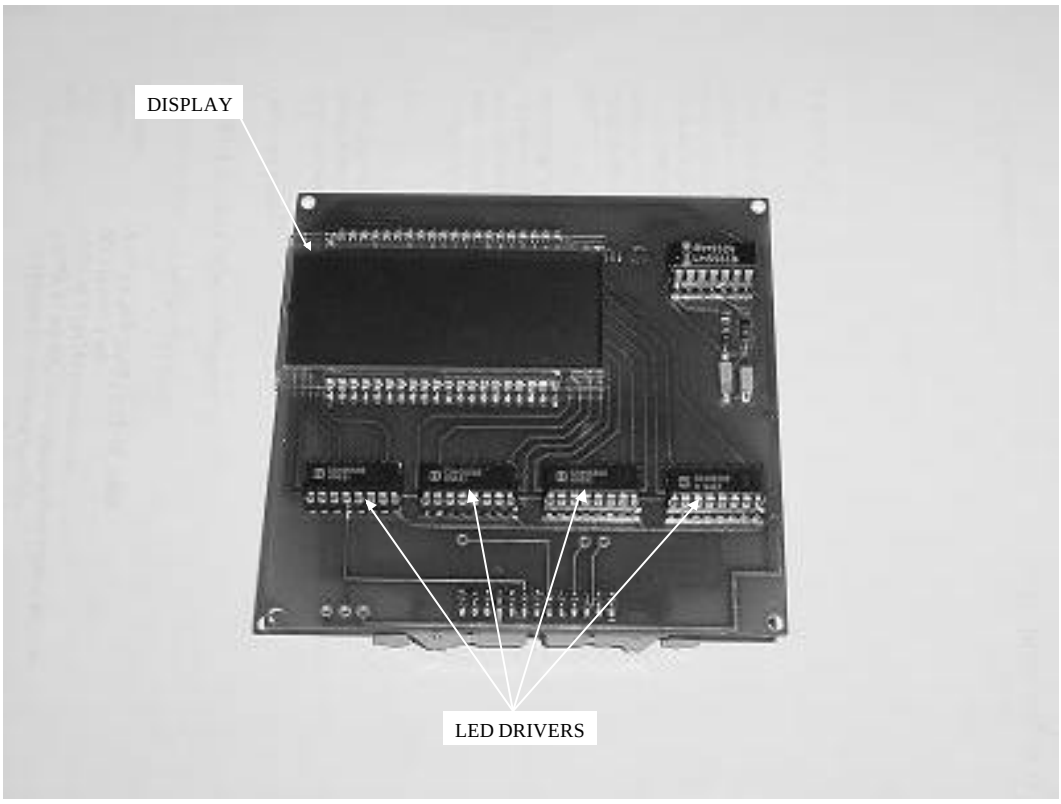


Figure 4.2: LED Display

Project "TryREADOUT":

The second step in developing the software was to try and connect the board to a 4 digit LED display (Figure 4.2). The result was the code listed in Appendix B – "TryREADOUT" which consists of "main.c" and "appconfig.c". The main subroutine is rather simple. Ports B and D, required for control of the LED display are initialized, and a number (in this case "123") is output to the display. Each digit of the display receives a binary input over four pins. If pin one for a digit is high, then it reads one, if pin four is held high, it reads eight, and so on. Values above nine are received as errors. Pins 0 through 3 of port B are connected to the ones digit of the display. Pins 4 through 7 of port B are connected to the tens digit.

Pins 0 through 3 of port D are connected to the hundreds digit. The final digit is held to ground (and therefore reads zero) which explains the reading seen in Figure 4.3.

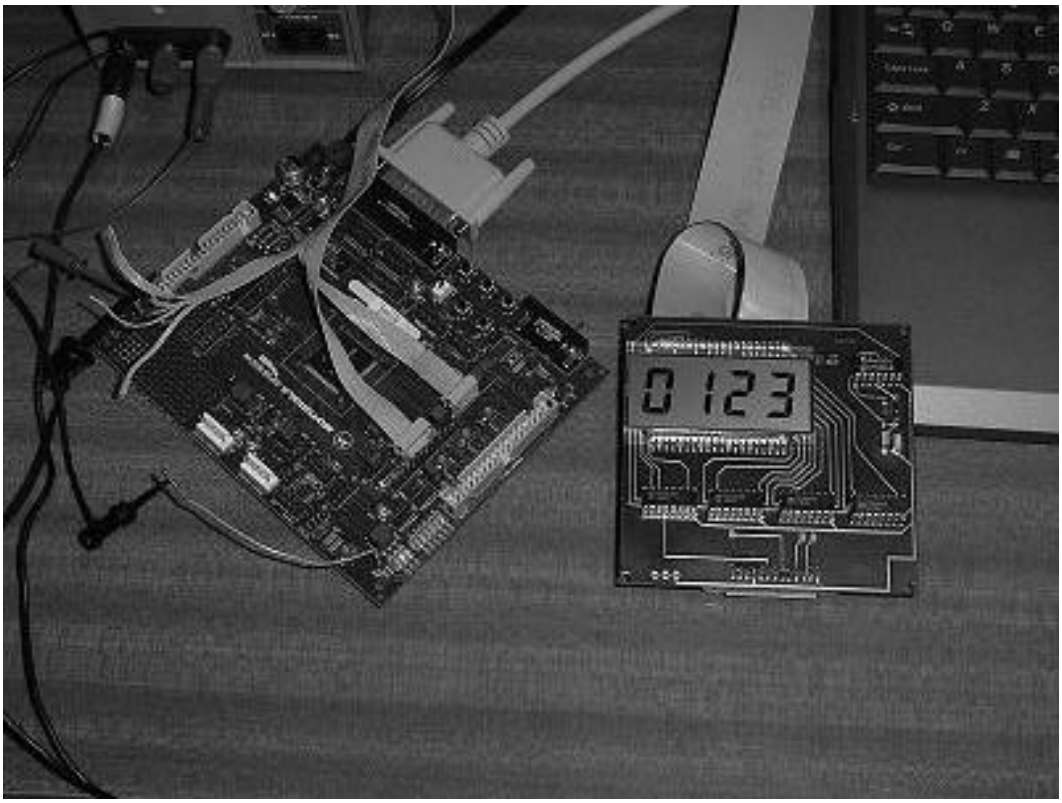


Figure 4.3: Operational LED Display

Since onboard power is not ample enough to drive the display, a power supply was connected separately. The test bench for this set up can be seen in Figure 4.4.

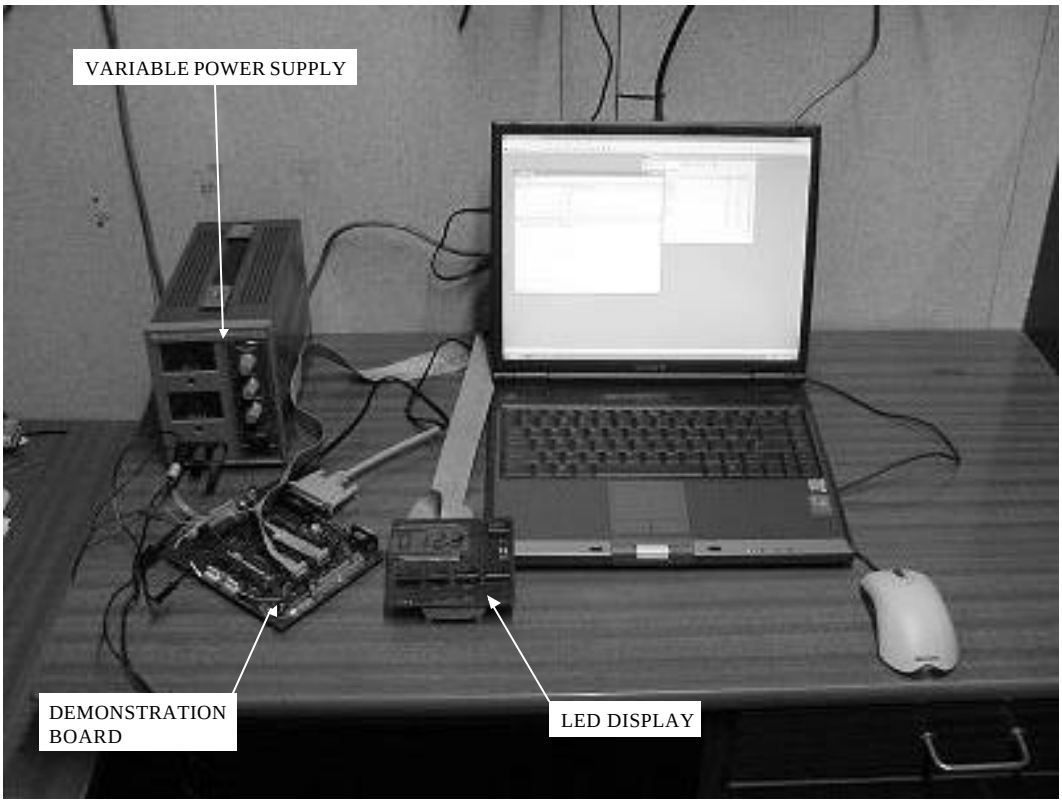


Figure 4.4: LED Test Set Up

Project "Serial test":

This program enables the controller to receive a character via the serial port and outputs "Hello" as the response. The code can be found in Appendix C – "Serial test", which contains "main.c" and "appconfig.c". Subroutine "main.c" initializes the serial port and declares three call-back functions for receive, transmit and exception interrupts. The only one used in this case is "sciRxCallBack" which is called when an interrupt is triggered upon receiving "SciReadLength" number of characters. The subroutine then outputs "Hello" via the serial port. All communications were done using Windows HyperTerminal.

Project "LabViewGPIO":

With a basic understanding of setting up serial communications and the ability to implement a digital counter, the next step was to combine the two and construct a topside display using LabView. The results can be found in Appendix D – "LabViewGPIO". Appendix D includes the c code, "main.c" and "appconfig.h", as well as the LabView panel and diagrams.

This program was developed in a simplistic manner and does not use interrupts to trigger a count. Instead, it reads the I/O port connected to the counter and calls subroutine "COUNTRECEIVED" if the pin is held high. Smoothing is done by installing a quarter second pause. This set-up works ok for a simple program such as this, but when multiple operations are brought together such as on the completed baseline system, interrupts have to be used and prioritized to make the system work.

Following through the code, "main.c" initializes the serial port and GPIO ports as in the previous sections. An LED is still used as a debugging tool to ensure the counter is working. A continuous while loop comprises the GPIO read and calls subroutine "COUNTRECEIVED" if the pin registers high. This subroutine first calls subroutine "TURNSCOUNT" which appends the two count strings: "digittens" and "digitones". It then constructs the string to be sent ("goingout") by appending the ones digit to the end of the tens digit. The constructed string is sent via the serial port.

The LabView display shown is an example supplied with LabView 5.0 called "Serial Read with Timeout". No modifications were made at this point to the supplied example program.[1]

Project "adctest2":

Having developed the basic structure of the software, the final two tasks that remained were to test the ADC and DAC capabilities of the controller. To simulate a strain gage, a variable resistance pot running off of board power was attached to ADC channel 0 (Pin 1, J9). This simulated a variable voltage input with a range of 0 to 3.3 VDC. The resulting code is found in Appendix E – "adctest2". This contains the c code, "adctest2.c" and "appconfig.h", as well as the LabView panel and diagrams. Once again, the LabView example, "Serial Read with Timeout" was used to view the results.

Walking through "adctest2.c", the first major definition seen is "sadc1", which is an adc_sState constant, defining the configuration when opening the ADC port. The second definition is "Data1", which is an ADC channel structure. This defines the buffer where information from the ADC port is stored. The constant definition that follows is for "low2Threshold". The yellow LED turns on and off when the value read at the ADC port falls below this constant. It was used primarily for debugging purposes.

Continuing into the main routine, the serial port is initialized, the ADC port is opened, and the GPIO ports are initialized. An ADC read is then started and if the buffer length is greater than zero, the value is sent via the serial port. Note that the value is calibrated by dividing by 10.853. It was assumed that code might be used for reading a pressure value from 0 to 3000 psi (standard pressure range on an ROV hydraulic system).

The code then turns the yellow LED on or off depending the reading from the ADC port. Finally, it resets the synchronization flag (if a read did occur) and initiates another ADC read. This re-initiation of ADC reads is necessary because of the set-up in "appconfig.h". When viewing this file, it can be seen that the ADC scan mode is defined as sequential once. This means that the controller will step

through all of the configured ports (in this case, only Port 0) sequentially and only one time. Therefore, processing power is not wasted by continuously reading the value. Also defined are the number of samples taken and the callback (interrupt) mode. The interrupt mode defines when the ADC triggers an interrupt. This can be triggered by a high or low threshold setting, a zero crossing, or it can just return raw data in which the interrupt resets are more or less done manually in the code as is shown here.

Project "TryDAC":

The final step before assembling the pieces was to test the DAC on the controller. This was simply done by using an example program provided with the SDK. The code can be found in Appendix F – "TryDAC". This contains the c code "TryDAC.c" and "appconfig.h". Routine main opens the DAC port, defines a value to be written, and writes that value to the DAC channel (in this case channel A). Values were read using a multimeter at Pin 0, J20.

Conclusion:

These initial developments provide a subroutine base for assembling the final baseline control system. They also presented an opportunity to learn the proper programming methods for the DSP56F805 microcontroller. A good learning example is the while loop used to read the counter in Project "LabViewGPIO". This worked for a single function program such as this. When this was tried in the baseline system where serial communication, analog inputs, and other functions are vying for processor time, a runtime error occurs. The proper method for accomplishing this sort of multitasking is through the use of the interrupt drivers.

This programming approach was easily remedied during the initial development. If the step by step approached had not been used, debugging that runtime error would have been much more difficult in the combined system. Progressive programming techniques such as these help the programmer save time and develop logical software structures.

Chapter 5
Description of Valve Pack

The baseline control system designed for this thesis was developed to control an ROV operable torque tool. The subsea control hardware required for this "smart" torque tool includes the controller SBC (single board computer), a proportional hydraulic flow valve for controlling the rotational speed, and a proportional hydraulic pressure valve for controlling the output torque. This chapter will describe the hardware designed for this thesis. Appendix G contains the mechanical drawings, a hydraulic schematic, and an electrical schematic to construct the necessary hardware.

A controller pack has been designed to meet the control requirements. This valve pack consists of a machined manifold, the controller card, a proportional pressure reducing valve, and a bi-directional, proportional flow control valve, along with the necessary hydraulic and electrical fittings. The entire pack is designed to be filled with dielectric oil for pressure compensation to eliminate the need for a bulky, one atmosphere housing. O-ring groove and SAE porting parameters were taken from the Parker O-Ring Handbook.[1]

The torque tool control system is designed for a depth of 10,000 fsw (feet of seawater) so it must withstand pressures up to 4,610 psi. The controller card depth is limited solely by the crystal. To solve the depth problem, a process of potting the crystal in epoxy has been successfully used in the offshore oil and gas industry.

The valves and associated amplifier/controller cards were tested and are operational to this depth. The specified flow control valve is a Wandfluh NG4-Mini proportional directional valve (P/N VWS4-D42-08-TF-G12) with a nominal flow rate of 2 gpm (gallons per minute) and a maximum operating pressure of 3600 psi.[2] The proportional pressure valve is a Wandfluh screw-in cartridge,

proportional pressure reducing valve (P/N MVP-PM18-200-G12) with a maximum flow rate of 5 gpm and a maximum operating pressure of 5800 psi.[3] These two valves are controlled with a Wandfluh proportional amplifier card (P/N P02A01D33) that is mounted directly on the valve. If the P02 card is configured for a variable voltage control input, it requires a 0 to 8 volt signal for the entire range.[4] The DAC (digital to analog converter) chip that supplies the analog output signals on the SBC controller card is the Maxim MAX5251. It is only capable of an output voltage of 0 to 3 volts.[5] To get this to work, the Maxim DAC can be set up with an external resistor as a digital programmable current source.[6] This can then be connected per the Wandfluh specification[7] to drive the P02 amplifier card. See the electrical schematic (Drawing # SSE-ELEC-0003) in Appendix G for more details.

Power and telemetry enter the unit from the backside through a port labeled "ELEC". The amplifier cards and controller board require 12 volts DC at 3 amps and a two wire RS-232 connection is needed (this can be upgraded to support the CAN protocol). Sensor signals enter from the tool through the port labeled, "To Tool". These lines carry signals from the Hall Effects sensors and strain gauges. The lines can be upgraded to include a pressure transducer and flow meters that can be implemented in a control loop.

The use of this system is as follows. The proportional pressure reducer reduces supplied system pressure to the torque tool and controls the output torque. An API Class 3 torque tool has a range of 0 to 1000 ft-lbs[8] and a typical hydraulic supply is 0 to 3000 psi. The flow control valve determines which way the tool rotates along with the speed. The following figures display the valve pack assembly and controller board. Appendix G – Valve Pack contains figures, machine, electrical, and assembly drawings allowing construction of the pack.

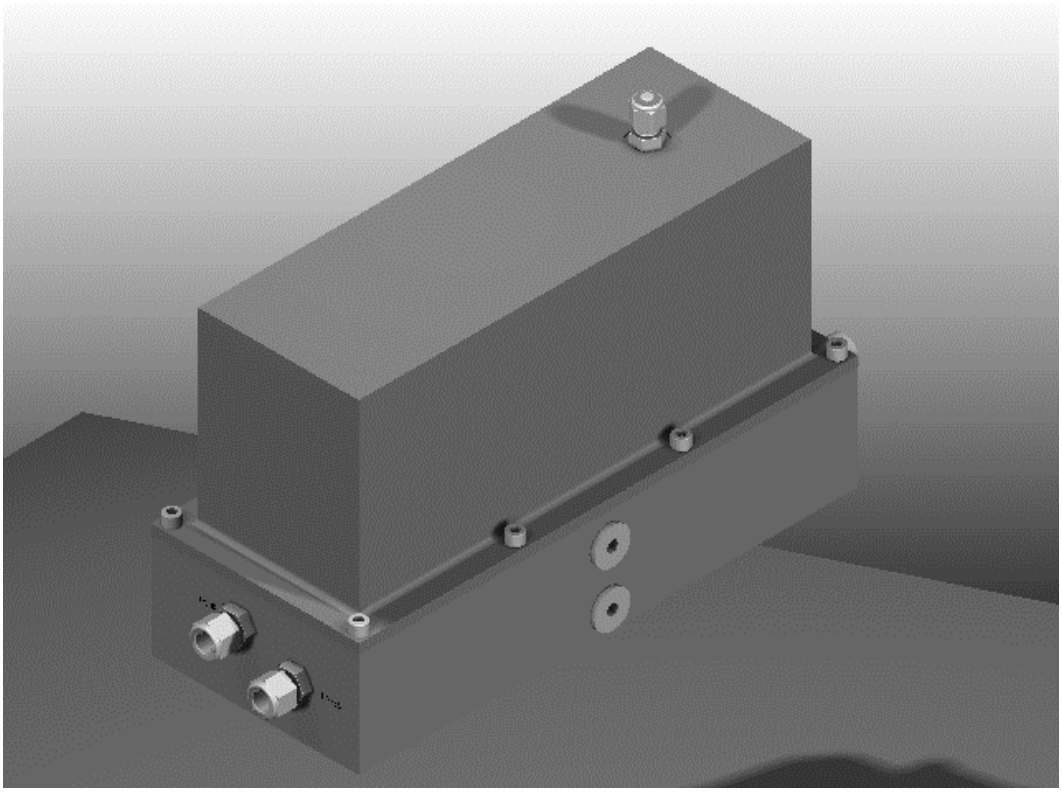


Figure 5.1: Valve Pack Assembled

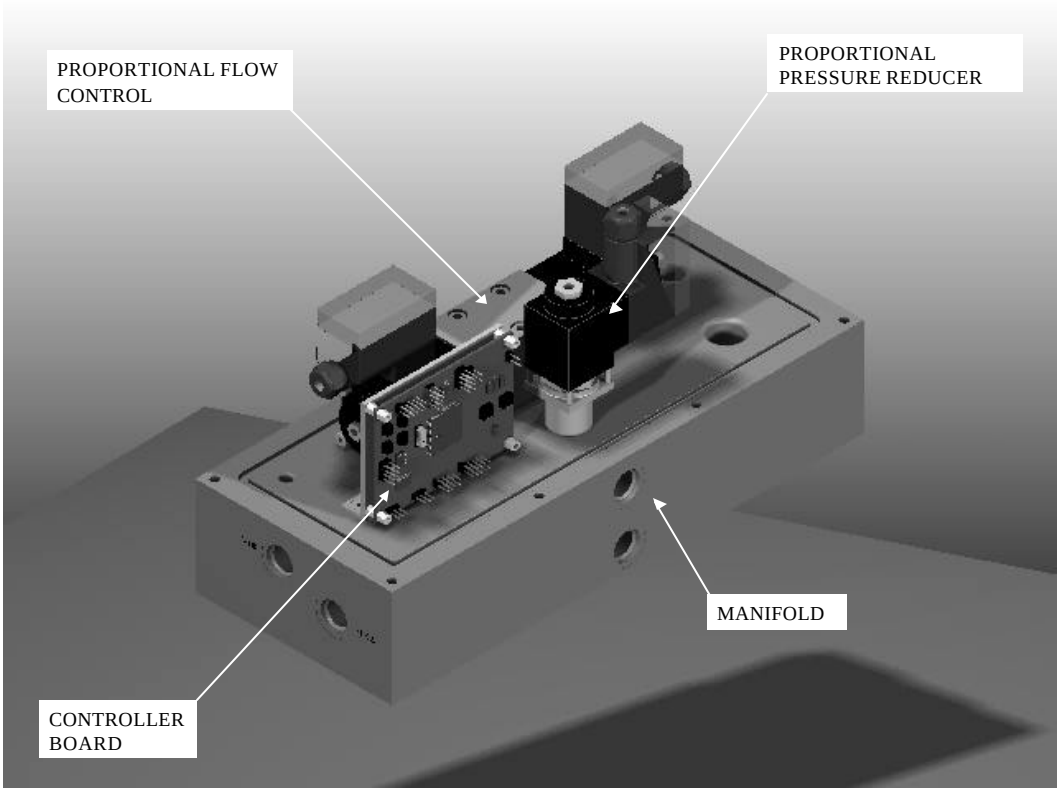


Figure 5.2: Valve Pack, Exploded View

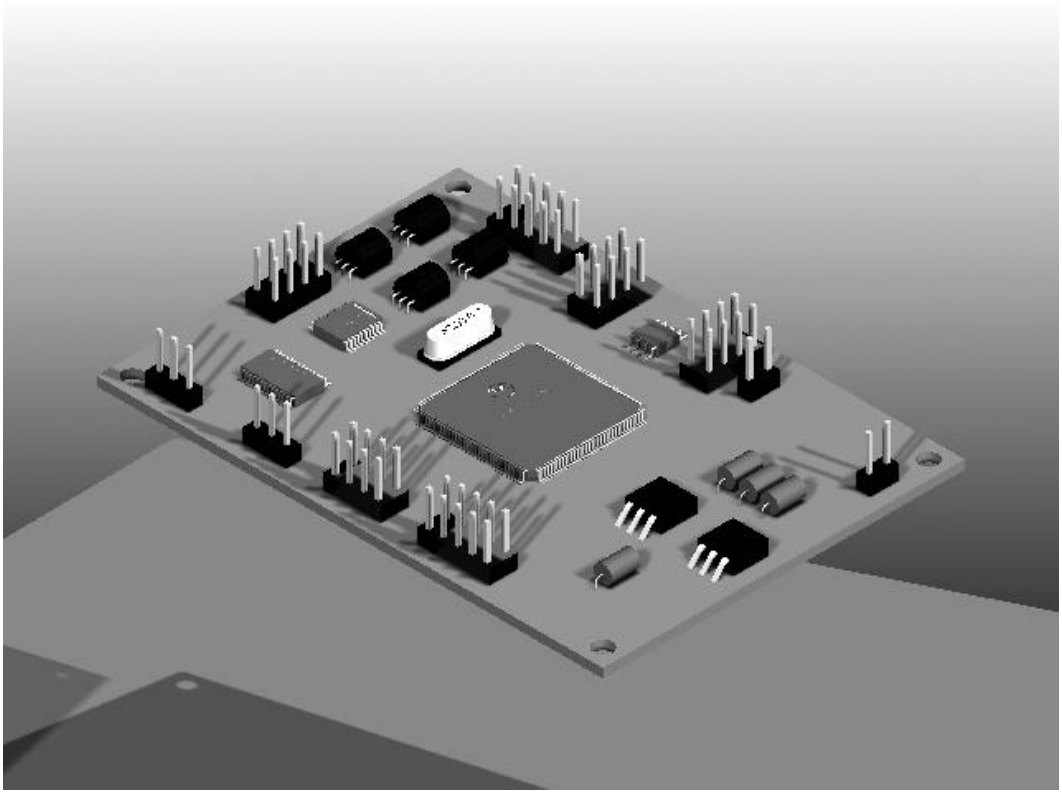


Figure 5.3: Controller Board

Chapter 6
Explanation of Torque Tool Control System C Code

The initial development work described in Chapter 4 laid the groundwork for assembling the final baseline system. The functions and subroutines were developed during this phase to perform analog and digital I/O and serial communication. The next major step was to combine these pieces of code along with the necessary timing structure to create a workable baseline control system. Chapter 4 discusses the use of while loops and built in pauses to smooth data collection and timing. The final system required the use of interrupt drivers and priority settings to create the real time, multitasking control program presented in this chapter.

The C code, LabView panel and LabView diagrams can be found in Appendix J – Baseline System. This includes the C code "Put It All Together.c" and "appconfig.h". The intention of this software is to meet the requirements as laid out in Chapter 3 for the subsea portion of the baseline system. To reiterate, these requirements are:

Turns count information displayed either via an LED or transmitted to the surface.

Turns counter (Hall Effect or reed switch) input – digital I/O.

Torque (strain gage) input – analog I/O.

Communication link for relay of information such as pressure and flow.

To better explain the software developed for this thesis, it is easiest to "walk" through the code step by step. Walking through "Put It All Together.c",

global numeric and string variables as well as functions are declared. As in the earlier ADC example, the adc_sState constant, "sadc0", is defined which configures the ADC port during an open call. "Data0", an ADC channel structure which describes the ADC storage buffer, is then defined. Moving into function main, the DAC port is opened and then "ConfigSerial" is called. This function configures serial port 0 for 8 bit words, no parity, and 9600 baud rate. It then declares "sciRxCallBack" as the receive interrupt callback function which is called when the controller receives "SciReadLength" number of characters. In this case "SciReadLength" is set to 1.

Back in function main, "ConfigGPIOPort" is called to configure the GPIO ports. In this subroutine, the character string "TurnsCounterString" is initialized to "C0000", GPIO port D, pin 0 is opened, and interrupts are enabled. The serial communication method used in this software does not send all information values continuously. Instead, it only sends values when there is an updated value. In this case, the controller would only send the value of the counter if a new count is received. In order to differentiate multiple strings, a simple addressing scheme was implemented in which the count string is preceded by a "C", the torque string by a "T", and the pressure string by a "P". In a more complicated system, a different addressing scheme would have to be used. However, for the current example, this method proved sufficient and easier to use while debugging.

Function main then calls subroutine "ConfigADCPort". This opens the ADC port per the configuration in sadc0, initializes the synchronization flag, and instructs the ADC to proceed with the first read.

"ConfigTimer" is then called to configure the timer which determines how often the ADC port is read. It creates a timer, "Timer1", which triggers an interrupt a quarter second after the program has started and every quarter second thereafter. When the interrupt is triggered, the function "Timer1ISR" is called. This in turn calls the function "ReadADCChannel".

Finally, function main installs the interrupt routine, "COUNTRECEIVED_ISR", which is called when an interrupt is triggered at GPIO port D (which is anytime the Hall Effect sensor pulls pin 0 high). A continuous while loop is inserted at the end.

Moving down in the code, "COUNTRECEIVED_ISR" clears the Port D interrupt that initiated the call, and then disables port D interrupts. This is done to prevent an interrupt from triggering while the subroutine is running. It also has a smoothing effect on the output and prevents accidental and unwanted counts. It then adds one to the turns counter variable and calls the function "CreateStringFrmDigits". This function is used multiple times in the program and is used to create a four character long string from a four digit number. The string "TurnsCounterString" is then defined as this newly created string, preceded by a "C" (the identifier mentioned above). A quarter second pause is inserted and then Port D interrupts are re-enabled.

Subroutine "CC_CallBack" is defined in "appconfig.h" to handle the ADC conversion interrupt as described in Project "adctest2", Chapter 4. "ReadADCChannel" is called every quarter second by the timer interrupt. This reads the information in the ADC buffer and determines if a read did occur based on a buffer length greater than zero. It then converts the value to a string using the "CreateStringFrmDigits" function and defines this string, preceded by a "T", as the torque string to be sent. The three strings, "ADCString", "TurnsCounterString" and "PressureString" are then written to the serial port. Finally, the synchronization flag is reset and a new ADC read is initiated.

Subroutine "sciRxCallBack" is called when the buffer receives a specified number of characters (in this case, 1) and an interrupt is triggered. It then reads the buffer and performs a check in the first set of if else statements. If the buffer contains a character value of "P", "A", or "B", the following characters to be read correspond to pressure, A side flow, or B side flow. Two counters are then

initialized to manage the construction of the strings. Counter "m" determines which string is currently being read (m=1 refers to pressure, m=2 to A side flow, and m=3 to B side flow). Counter "n" determines how many characters of the string have been read. Based on these counters, the three functions "ConstructPressureString", "ConstructASideString" and "ConstructBSideString" are used to assemble the individual strings. Again, a simple addressing scheme is used in which the pressure string starts with a "P", the A side string with an "A", and the B side string with a "B". At the end of each read from the serial buffer, a command is issued to clear the buffer.

In the final if statement of each of the "ConstructString" functions, is a call to the subroutine "SetDACOutput". This function reads the counter "m" to determine which value it's re-issuing and then converts the corresponding string to an integer. This value is re-calibrated for a range of 0 – 65535 (the resolution of the DAC channels) and then output to the corresponding channel.

Conclusion:

"Put It All Together.c" combines the requirements laid out at the beginning of this chapter into a C program capable of real time control. The code allows for proportional speed control of a torque tool in two rotational directions as well as proportional control of output torque through the use of a pressure reducing valve. This rotational motion is monitored by the use of a turns count Hall Effect sensor and the torque via a strain gauge. All of this information is transmitted by way of an RS-232 serial link.

The following chapter will detail the topside portion of this torque tool control system at the other end of this serial link. The topside graphical user interface (GUI) has been written using LabView software and provides a method of user input and status monitoring.

Chapter 7
Explanation of Surface Control Unit Graphical User Interface (GUI)

The majority of this paper is dedicated to the development of the vehicle portion of the torque tool control system. However, the graphical user interface (GUI) is the portion of the system most evident to the operator. The real time operating system VxWorks from WindRiver was investigated because of its acceptance in industry and advertised quick development time.[1] However, the cost of such a system was beyond the budget of this project. The topside control interface must be user friendly so a Windows environment was selected because of its widespread familiarity. A number of programming languages are available to develop a Windows GUI such as Visual Basic and Visual C++. LabView was finally selected because of past experience with the software and because it is intended for the development of industrial control systems.

This chapter will describe the topside portion of the torque tool control system that was programmed using LabView. The LabView documentation can be found in Appendix J – Baseline System. Viewing the LabView panel, it can be seen that the user controls are pressure, flow side A, and flow side B along with the associated submit control buttons. The readout indicators are pressure, torque, and turns count. Further readouts are classed under a "Diagnostics" section and include the raw string being transmitted from the LabView application, the string being received, a telemetry error indicator, and a telemetry timeout indicator.

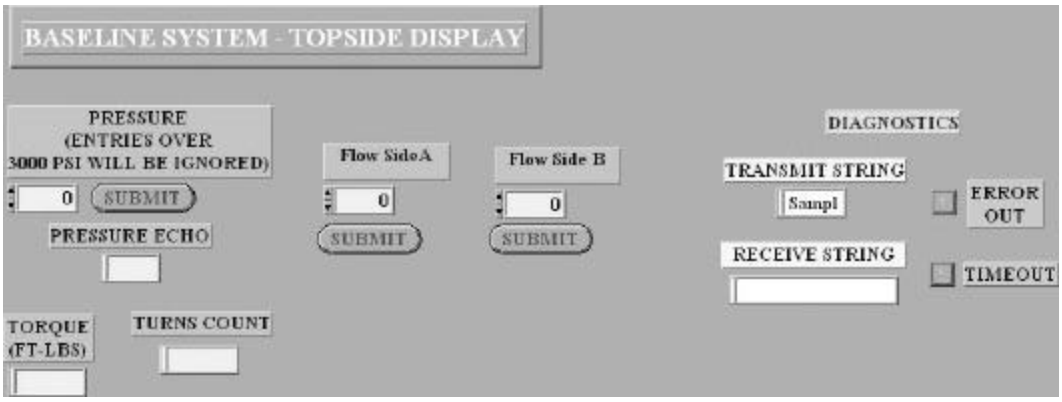


Figure 7.1: Topside GUI Window

The user can enter any value from 0-3000 psi into the pressure digital control and press the associated "Submit" button. Values over 3000 will be interpreted as 3000. The software then sends this value via the serial port to the valve pack controller board. The bottom side controller echoes this value back which serves as an error check to ensure the number was received. Further error checking is available by use of the strain gage/torque reading set-up. The bottom side controller, by way of a strain gage, reads the actual torque output of the tool and transmits the value top side via the serial port. This value is displayed in foot-lbs and can be visually compared to the current pressure setting.

Rotational speed of the tool is controlled with the two controls labeled "Flow Side A" and "Flow Side B". The value is entered as a percentage (0-100) and transmitted bottom side via the serial port. No feedback is currently enabled due to the fact a visual determination of speed can be made by observing the tool. However, it is recommended that this feedback be installed as an upgrade.

The "Diagnostics" section aids in any troubleshooting and allows the operator to check readouts with the actual strings being sent and received. The "Transmit String" indicator displays raw data being sent from the topside computer via the serial port. "Receive String" shows the raw data coming in. "Error Out" indicates if an error has occurred with a serial port connection or link up with the

bottom side controller. The "Timeout" indicator will display if the serial port attempts to connect with the controller but does not succeed within the specified amount of time.

All serial programming is based upon the serial communications examples provided with LabView. LabView Version 5.1 was used for this project.[2]

Explanation of Diagrams:

In order to enable the multiple serial sends and reads, a series of case structures were used. Moving from the outside in, the first case structure is attached to the Flow Side B submit button and labeled "CASE STRUCTURE 1". When true, this triggers a serial initialization with a 9600 baud rate, a buffer size of 5 characters, port # 0 (comm port 1), 8 data bits, and 1 stop bit.

An error code is associated with the next case structure labeled "CS 2". This error code registers a "1" if the baud rate, data bits, stop bits, or port number are out of range. "CS 2" will then follow the true value which causes the transmit string value to be set to zero and the "Error out" indicator to light.

If the error code does not light, the false path of "CS 2" is followed and the string conversion and send processes are started. For the three strings sent (Flow Side A, Flow Side B, and Pressure) this process is the same. First, the decimal entered at the user control is converted to a string. Then, a series of nested case structures are used to concatenate the string with the proper identifier and number of zeroes to make the string the correct form. For Flow Side A and B, the proper output would be of the form "AXXX" or "BXXX", where "XXX" is the percentage value being transmitted. For Pressure the proper output would be of the form "PXXXX", where "XXXX" is the pressure value being transmitted.

Using Flow Side B as an example, a comparison is made to see if the string length is greater than 1 and the result is used in the case structure "CS 3". If false

(not greater than 1), then the string is concatenated with "B00" resulting in the string "B00X". This string is sent via the serial port using the Serial Port Write VI (a LabView supplied VI) on port 0 (comm port 1). The string is also displayed in the "Transmit String" dialog box under diagnostics. The error indicator is attached to this write VI as well. The same errors mentioned above will cause the indicator to light.

If "CS 3" receives a true answer (the string is greater than 1), then it moves on to another comparison to see if the string is greater than 2. The same process is continued with "CS 4" and "CS 5" until the proper string form is assembled. All sent strings are displayed in the "Transmit String" dialog box and any errors in serial communication result in an error out light.

Moving back to the outermost case structure "CASE STRUCTURE 1", it can be seen that if it receives a false result, a similar set of case structures is embedded that are tied to Flow Side A. These case structures, "CS 6", "CS 7", "CS 8", "CS 9", and "CS 10", perform a serial write of the Flow Side A user entered value if "CS 6" receives a true value. This serial write and the above mentioned case structures perform exactly as those described for Flow Side B above.

If "CS 6" receives a false answer, another set of embedded case structures performs the same function for the Pressure value. These structures are labeled "CS 11", "CS 12", "CS 13", "CS 14", "CS 15", and "CS 16". If "CS 11" receives a true value, the above mentioned case structures will enable a serial write of the Pressure user entered value.

Finally, the while loop "WHILE LOOP 1" is encountered if "CS 11" is false. This while loop and the associated embedded case structures perform a serial read at port 0 (comm port 1) while the timeout limit is not reached. If the timeout limit is reached, the while loop will not execute and the "Timeout" indicator will be lit.

If the serial port is operating ok, the while loop is executed and the Bytes at Serial Port VI (again, supplied with LabView 5.1) will count bytes received at the indicated port (in this case port 0). If the required byte count (20) is not reached, "CS 17" will register false and "CS 18" and "CS 19" will perform a timeout check and a wait. If the error still exists, no read will be performed and the "Error out" light will be lit.

If the proper numbers of bytes are received, "CS 17" will follow the true execution. The Serial Port Read VI (supplied by LabView) is used to read the indicated number of bytes at port 0. This string is displayed in the "Received String" dialog box. A series of match pattern functions are used to check the identifier and the associated value is displayed. The identifiers are "P" for the pressure value, "C" for turns count, and "T" for the torque.

Conclusion:

LabView software was used to create a user friendly Windows type interface that allows for the real time control of an ROV torque tool. This interface allows the operator to set the hydraulic pressure and flow of the tool, which controls the tool's torque and speed respectively. The GUI displays the current torque output and turns count. Other information such as an echoed current pressure setting and received telemetry string are also displayed to aid in troubleshooting. This interface is laid out in a single window format with relatively easy to use controls.

Chapter 8
CAN Overview

Control Area Network, or CAN, was developed by Bosch in the 1980's and first published in 1986. Version 2.0 or the extended version was released in 1991.[1] In the Open Systems Interconnection standard, CAN is a low level communication protocol requiring a higher layer protocol to make a complete communication system. CAN was created specifically for vehicle networking, an environment with a high level of electronic noise and a great need for reliability. It is used in applications such as anti-lock brake, engine control and body electronics systems. The protocol allows for bit rates up to 1Mbit/s and because it uses a single common bus, permits the elimination of a complicated wiring system.[2]

This chapter will present an overview of the CAN protocol so that the reader may have some basic knowledge of the standard. This will allow for a more thorough understanding of Chapter 9, which describes how the torque tool control system may be expanded to control a more complicated system such as a work class ROV.

The Open Systems Interconnection standard defined a basic structure for a communication system. CAN is a low level communication protocol, meaning that it must be used with a higher layer protocol in order to have a complete, workable system. The OSI model will be described below to understand where the CAN protocol fits in.

Open Systems Interconnection

The Open Systems Interconnection (OSI) standard is a reference model to describe how data moves between two computers or nodes in a communications network. It was developed in 1984 by the International Organization of Standards (ISO) and serves as the prime outline for computer network systems.[3] The model divides the overall task into seven separate layers[4]:

Application, Layer 7
Presentation, Layer 6
Session, Layer 5
Transport, Layer 4
Network, Layer 3
Data Link, Layer 2
Physical, Layer 1

The upper, or high, layers are termed application layers. These include application, presentation and session. The lower layers are dubbed data transport layers that consist of transport, network, data link, and physical.

The physical layer defines the actual physical link between the networked computers. This portion of the model defines items such as connector style, voltage levels, and communication timing. Ethernet defines a physical layer since it defines whether a twisted pair or coaxial cable should be used for the protocol.[5]

The data link layer handles transmission reliability issues such as error notification, physical addressing, data flow, and data sequencing. The data link layer is divided into two sub layers: logical link control (LLC) and media access control (MAC). The LLC layer is defined under IEEE 802.2 and defines services for data transfer and remote data requests.[6] The MAC layer is responsible for the

transfer protocol, and also assigns MAC addresses that are used by some protocols to identify individual nodes.[7]

The network layer defines the layout of the network and network addressing. This layer can define how nodes are addressed on the network (as opposed to the MAC address) and the routes that messages are transmitted across a network.[8]

The transport layer is responsible for data transmission, flow control, and the multiplexing of data. This layer takes is responsible for proper transmission rates and transmission error checking. TCP and UDP are both transport layer protocols.[9]

The session layer controls the actual communication session. This layer ensures the synchronization between communicating devices such as the three-way handshaking method that TCP/IP uses.[10]

The presentation layer ensures that data conforms to a format acceptable by the receiving computer. Common presentation formats include JPEG, MPEG, and TIFF that are accepted by a number of computer systems.[11]

The application layer is an umbrella definition of anything outside the OSI definition that is required to interact with the current application. This includes any software necessary to prepare the data for processing by the user application.[12]

CAN as a Low Level Protocol

As mentioned above, CAN is a low level protocol. It only defines communications at the physical and data link layer levels. Per the OSI standard, the data link layer is divided into the LLC and MAC layers. The Bosch CAN specification defines the scope of these layers as the following[13]:

The physical layer defines how signals are actually transmitted and therefore deals with the description of bit timing, bit encoding, and synchronization. Within this specification, the Driver/Receiver characteristics are not defined so as to allow transmission medium and signal level implementations to be optimized for the application. Within one network, the physical layer must remain consistent from one node to the next.

The MAC sub layer represents the kernel of the CAN protocol. It presents messages received from the LLC sub layer ad accepts messages to be transmitted to the LLC sub layer. The MAC sub layer is responsible for message framing, bus arbitration, data acknowledgement, and error detection and signaling. This sub layer is supervised by a management entity called fault confinement which is a self-checking mechanism fro distinguishing short disturbances from permanent failures.

The LLC sub layer is responsible for message filtering, overload notification, and recovery management.

Since CAN only defines the lower two layers, a higher-layer protocol (HLP) is required to construct a complete network communications system.

Basic CAN Concepts

The method of communication used on the CAN bus is called “broadcast”. This means that no message is sent to a single node address. Instead, data is broadcast along a common bus to all nodes, which then determine, according to the identifier preceding the data, whether the information is pertinent to that particular node. Ethernet is set up to use broadcast communication as well as multicast (address groups) and unicast (single address). TCP/IP protocol and USB use point to point communication meaning messages are sent to single addresses. The advantage to the broadcast method is that a command requiring action from

multiple nodes can be sent once and avoid unnecessary use of the bus. Depending on whether standard frames (CAN 2.0A) or extended frames (CAN 2.0B) are being used, the identifier is 11 or 29 bits long, respectively.

FRAME TYPES –

There are four types of data frames that can be broadcast[14]:

Data frame

Remote frame

Error frame

Overload frame

The data frame can be broken down into seven fields: start of frame, arbitration, control, data, CRC, ACK, and end of frame. The start of frame (SOF) field is a single dominant bit. The arbitration field in the standard format contains an 11 bit identifier followed by the remote transmission request (RTR) bit which is dominant. In extended format, the arbitration field consists of an 11 bit base identifier, a substitute remote request (SRR) bit which is recessive, an identifier extension (IDE) bit that is recessive, and an extended identifier of 18 bits. The control field is six bits long and contains the 4 bit data length code that defines the length of the data field. The data field is the actual data being transmitted and can be anywhere from 0 to 8 bytes in length. The CRC (cyclic redundancy check) field contains the CRC sequence (derived from a CRC polynomial calculation) and a CRC delimiter that is recessive. The ACK (acknowledge) field is two bits long and contains the ACK slot and ACK delimiter both of which are recessive for the transmitter. Any receiver that receives the data field correctly according to the CRC check will superscribe a dominant bit into the ACK slot. Finally, the end of frame sequence consists of seven recessive bits.[15]

The remote frame is similar to the data frame with two differences: the RTR bit is recessive and there is no data field. This frame type is used as a request for information. Typically the identifier is the same as that of the data being requested. The data length code must be identical to that of the data being requested for the request to be accepted.[16]

Any node that detects a transmission error on the bus transmits an error frame. An error frame consists of an error flag and an error delimiter. An error flag can be either active (6 consecutive dominant bits) or passive (6 consecutive recessive bits). Because of an error checking method called "bit stuffing", six consecutive bits of the same value are not allowed; therefore, the transmission of an error flag causes all other nodes on the network to transmit their own error flag. The superposition of all error flags will be anywhere from six to twelve bits long. After the transmission of an error flag, each node starts transmitting recessive bits until it receives a recessive bit. This means all nodes have stopped sending error flags. Once a recessive bit is detected, seven more recessive bits are sent. At the completion of an error frame, the transmitter that was interrupted will attempt to re send its data.[17]

The overload frame is sent by a node that has received data beyond the capacity of its receive buffer. It conforms to the structure of an error frame.[18]

BUS ARBITRATION –

Any node on the CAN bus may begin transmission of a frame when it detects intermission and an idle bus. Intermission consists of 3 recessive bits and the idle bus length is user defined. At this point, the possibility of multiple nodes transmitting simultaneously exists. Therefore, all transmitters monitor the bus level and if a dominant bit is received when a recessive bit has been sent, that node ceases its transmission. This prevents any loss of time due to different nodes fighting over the bus and provides a built-in method of message prioritization. A

dominant bit is typically logic zero; therefore, the frame with the lowest value identifier will win arbitration.[19]

The Ethernet and IEEE 802.3 protocols use a transmission scheme similar to CAN. However, bus arbitration in these two protocols does not use non-destructive transmission. In Ethernet, any node that detects a collision (two nodes broadcasting simultaneously) broadcasts a "jam" signal that causes all nodes to wait for a "backoff" period of time. Since this "backoff" time can be set as a random number or a varying number per node, message priorities can be set on a per node basis. Although both methods have good end results and overall transmission rates, the system used by CAN is much more efficient since it does not allow for time delays because of arbitration. Also, the CAN system is much more predictable since priorities are set by numeric message identifiers rather than a separate time delay.

ERROR HANDLING AND CONFINEMENT –

The CAN specification provides 5 methods of error detection. The first is bit monitoring and happens when a node sends a bit and monitors a different value on the bus. The exception to this error is when two nodes are in arbitration for control of the bus. The node that loses arbitration transmits a recessive bit and detects a dominant bit on the bus. This will not signal an error flag.

The second form of error handling results from "bit stuffing". During the SOF (start of frame), arbitration, control, data, and CRC fields, a transmitting node will place a complementary bit after a series of five identical bit values. This means that six consecutive bits of the same value will result in an error on the bus. The method of "bit stuffing" is not used during error or overload frames, as well as the fields not mentioned for the data and remote frames.

The third error handler is the CRC check included in the data frame. The CRC check is a polynomial calculation created from the de-stuffed bit stream

consisting of the SOF, arbitration, control, and data fields. The Bose, Chaudhuri and Hocquenghem (BCH) method is specified and results in a 15 bit CRC sequence.[20] Receiving nodes perform the CRC calculation and compare the result with the transmitted sequence. If the results do not match, an error frame is transmitted.

A form error occurs when a wrong value is monitored for a frame with a specified format. If a particular bit in a frame is supposed to be recessive and a dominant bit is monitored, an error is broadcast on the bus.[21]

The fifth form of error handling is the ACK slot. If a transmitter does not detect a dominant bit during this period, it assumes that no nodes received the transmitted message and an Acknowledgement error is signaled.[22]

Confinement of network errors is achieved through a method of error counting. Each node keeps two separate counts, transmit and receive. These are incremented according to a series of rules laid out in the CAN specification. As long as the counts remain below 128, the node is in an error active state. This means it can communicate over the bus normally and signal an active error flag when it detects a bus error. When either of these counts is greater than or equal to 128, the node enters what is called error passive state where it still has access to the bus but can only respond to errors with a passive error flag. If the transmit error count exceeds 256, the node becomes bus off which means it cannot transmit over the bus.[23]

BIT TIMING –

The CAN protocol does not have a provision for a global clock. Therefore, each node must have a local oscillator and system synchronization is done at the edge between changing bit values. As mentioned above, the maximum bus speed available is 1 Mbit/s dependent upon the oscillator selected. The nominal bit time, or the time for one bit to be transmitted over the bus, may be found by taking the

reciprocal of the bus speed. This nominal bit time can be broken down into 4 segments as seen below in Figure 8.1.

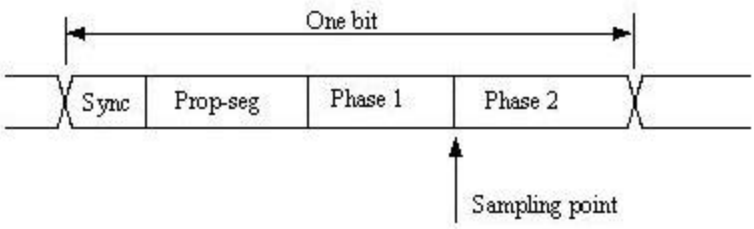


Figure 8.1: Nominal Bit Time[24]

The value of time quantum is derived from the nominal bit time. This value can be adjusted by a prescaler that is user programmable. There are anywhere from 5 to 25 time quanta in a bit time.[25]

The synchronization segment of the bit time is 1 time quanta in length. The edge of the bit is expected to fall into this period and results in a hard synchronization. The propagation segment is provided to make up for delay times within the bus. This segment may be anywhere from 1 to 8 time quanta in length.[26]

Both phase segments are adjustable in order to correct for a resynchronization, which occurs if the edge of the bit does not fall within the synchronization segment. Phase segment 1 may be shortened and has an overall length of 1 to 8 quanta. Phase segment 2 may be lengthened and its overall length is 2 to 8 quanta. Between the phase segments is the sampling point during which the value of that bit is read.[27]

The synchronization jump width (SJW) is defined as the maximum amount of adjustment allowed when correcting for a resynchronization. There are four user programmable values:

The SJW which has a value between 1 and the minimum of 4 and the length of phase segment 1.

The number of quanta before the sample point

The number of quanta after the sample point

The clock prescaler value

PHYSICAL ATTRIBUTES –

The signals transmitted across the bus are termed dominant and recessive. A dominant bit has a logic "0" value and a recessive bit has a logic "1" value. Nodes are connected to the bus such that a dominant bit will drive the signal even if all other nodes are transmitting a recessive bit.[28]

The most common used wiring scheme is specified under ISO 11898, which calls out a two-wire balanced signal. Approximate transmission lengths are[29]:

1 Mbit/s – 40 m

500 kbit/s – 100m

250 kbit/s – 200m

125 kbit/s – 500m

10 kbit/s – 6000m

Although there is no standard CAN connector, those typically used include a 9 pin DSUB, a 5 pin mini-c, and a 6 pin Deutch connector.[30]

Conclusion:

As can be seen in the preceding overview, CAN has multiple methods of error checking. This is one of the main reasons the protocol was selected and is important for a communications system being developed for a high noise, industrial environment. The protocol also allows for a simple method of adding new nodes to the system because of the "broadcast" message transmission method it uses. As a

result, items do not require individual addressing or other complicated identification schemes.

There are other protocols such as Ethernet and TCP/IP that have attributes similar to CAN. Ethernet uses the broadcast method with a common bus and has extensive error checking. However, the method of bus arbitration that Ethernet uses is more complicated than and not as efficient as the non-destructive method used by CAN.

TCP/IP uses point to point addressing and has extremely efficient message routing built in. If a node is offline or a part of the communication bus is congested, data packets can be sent via other routes. This type of system is ideal for an ever expanding network such as the Internet. An ROV, on the other hand, is unusual if it has more than thirty separate items requiring a control node on the network. An ROV control system would not make use of a multi-path wiring scheme allowing different routing of data because of the necessity to keep wiring runs (and thus failure points) to a minimum. Also, the broadcast method as opposed to individual addressing fits easily with an ROV's control signals. For example, an operator's motion on a joystick may require a number of thrusters on the vehicle to operate. This control signal may be sent once to all thrusters rather than multiple times to individual components.

The next chapter will describe how the torque tool control system can be expanded to control a work class ROV using the CAN protocol as the basis for a communication network. The higher layer protocol MSCAN (Motorola Scalable Control Area Network) will be described along with the basic structure of the expanded system.

Chapter 9
Expanded System

This chapter will present a theoretical layout of a work class ROV based upon the control system described previously in this paper. A work class ROV as defined under API specifications has dimensions greater than or equal to 86”x70”x95” and weighs over 5000 lbs..[1] These vehicles are also equipped with a robotic manipulator that is used to grab and move items or tools. The driving idea behind the design of this expanded system is that individual components of the ROV have their own controllers and software. These components can then be added or removed from the system more easily and, in the case of single component failure, the entire system is not brought down.

The CAN protocol presented in Chapter 8 is used as a communications link between these components. However, a higher-layer protocol (HLP) is necessary to create a full network system. The HLP designed for the DSP56F805 is called Motorola Scalable Controller Area Network (MSCAN).

Motorola Scalable Controller Area Network

MSCAN is an add-on module to the Embedded SDK for digital signal processors (DSPs). It is based upon the MSCAN12 definition first used on the MC68HC12 family controllers.[2] The module provides CAN drivers as well as functions written in C that allow the programmer to write code using the SDK environment. The drivers are written with a default setting such that the designer can begin creating the basic program without having to adjust more complicated settings such as bit timing, clock source, message filtering, or power states. These

static settings and program functions will be described below. First, an overview of some of the features offered by MSCAN will be presented.

MSCAN FEATURES

Motorola Scalable Controller Area Network adheres to CAN version 2.0 A/B. It supports both the standard 11 bit identifiers and extended 29 bit identifiers. Data messages can be anywhere from 0 to 8 bytes in length and bus speeds range from 10 kbit/s to 1 Mbit/s depending on the oscillator.

The DSP56F8XX family output a CAN signal directly from the controller. On the evaluation board used for this research, this signal passes to a Philips PCA82C250T transceiver that sends a two-wire, balanced signal in accordance with ISO 11898. The recommended connection of multiple evaluation boards (EVMs) in a common CAN bus can be seem in Figure 9.1.

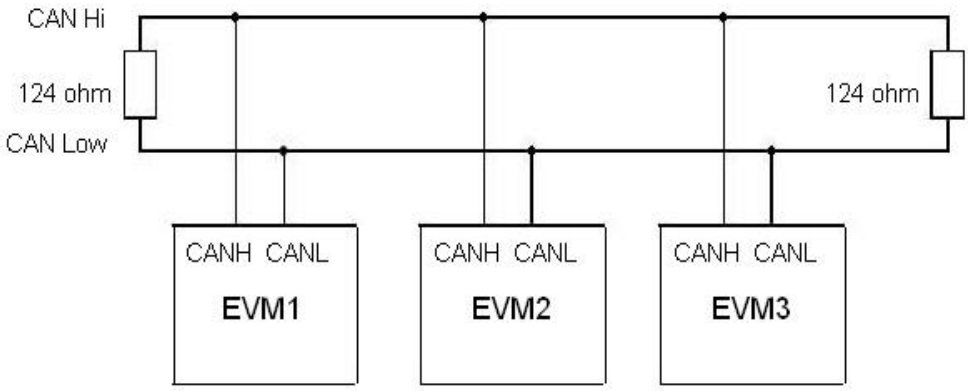


Figure 9.1: CAN Bus with Multiple EVMs (Evaluation Modules)[3]

MSCAN provides a multiple buffering scheme for sending and receiving messages as shown below in Figure 9.2. There are three transmitting buffers and two receive buffers. Transmit buffers signal they are ready to handle data by setting the associated TxE (transmitter empty) flag. Data can then be written to the

transmit buffer and the data will be sent when the bus becomes available. If multiple transmit buffers are full, the message with the highest priority will be sent first. The highest priority is determined by the message with the lowest numbered identifier.

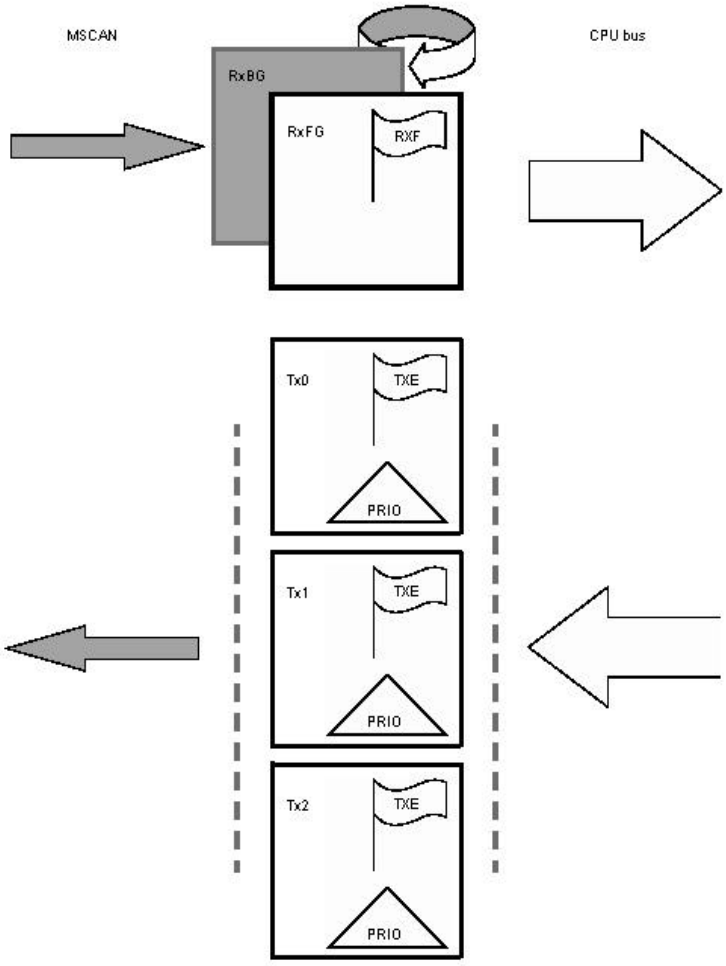


Figure 9.2: MSCAN Message Buffer Organization[4]

The two receive buffers consist of two MSCAN memory buffers that are mapped alternately to a single CPU (central processing unit) buffer. This means that only one of the buffers is accessible by the CPU at any one time. Incoming

messages that pass filtering parameters are written to the RxBG or background receive buffer. If the receiver full (RxF) flag is not set, the message is copied to the RxFG (foreground receive buffer), the RxF flag is set, and the message received interrupt service routine (ISR) is emitted. An ISR is a program function that is called as the result of an interrupt or trigger. In this case the ISR function would probably read the message, store any pertinent data to memory, and reset the RxF flag allowing any incoming messages to be written to the buffer. An overload error can occur when both the RxBG and RxFG are full and another message is received from the CAN bus.

MSCAN offers a message filtering scheme consisting 32 bit, 16 bit, or 8 bit filters. These filters define acceptable numerical patterns in the standard or extended identifiers.[5] Parts of the identifier may also be masked, or ignored, as defined by the particular filter.

Finally, three low power states are available. Sleep mode allows the MSCAN controller to finish current message operations and then cease bus operations. If any bus activity is detected, the controller will return to normal operations. The soft reset mode ceases any message activity immediately and puts the transmit pin in a recessive state. Initializations can be made during a soft reset. Power down mode is entered when the CPU is shut down. Soft reset and power down mode should not be entered unless the controller was previously put into sleep mode. Bus error could result if this is not followed.

MSCAN DRIVER DEFINITIONS

Motorola Scalable Controller Area Network has sixteen static definitions that can be declared to customize the communications for a particular application. As mentioned above, MSCAN has a default setup such that none of these static definitions are required. The default setting for the driver is[6]:

CAN 2.0A addressing protocol

11 bit Identifier length

Un-Queued message transmission mode

The driver can be set to operate in either CAN 2.0A or 2.0B addressing modes. This defines the identifier length to be either 11 or 29 bits long, respectively. Queued and Un-Queued mode means memory buffers are allocated for transmitted and received messages before they are written to the five MSCAN buffers (3 transmit and 2 receive). This is one of the settings that enable the programmer to control how much memory a particular application will require.

1 & 2 - CAN_MAX_RECEIVE_ID & CAN_MAX_TRANSMIT_ID:

These two definitions specify the maximum number of message buffers that can be open at one single time while in Queued mode. The maximum value for each is seven buffers meaning that seven messages can be waiting for transmit and seven messages with different identifiers can be received. This is separate from the multiple buffering scheme that defines two receive buffers and three transmit buffers. Those five buffers are actually located in the MSCAN hardware. The seven buffers declared by these two "MAX_ID" definitions are defined by software and allocated out of program memory.

3 through 8 - CAN BIT TIMING DEFINITIONS:

The MSCAN driver provides six static definitions to control the bit timing parameters. These are "CAN_SPEED", "CAN_TIME_SEGMENT1", "CAN_TIME_SEGMENT2", "CAN_PRESCALER", "CAN_SAMPLING", and "CAN_SYNCH_JUMP_WIDTH". "CAN_SPEED" allows the programmer to specify the bit rate of the application from nine predefined speeds ranging from 1 Mbits/s down to 10 kbits/s. If this setting is defined, the five other timing definitions cannot be used.

"CAN_TIME_SEGMENT1" and "CAN_TIME_SEGMENT2" define the length of the two time segments in clock cycles.

"CAN_PRESCALER" is used t set the multiplication value used to determine the minimum time quanta.

"CAN_SAMPLING" determines how many times the bus is sampled during a bit time. If set to "0", the bus is sampled once. If set to "1", three samples will be taken during a bit time to determine the actual value of the bit being sent.

"CAN_SYNCH_JUMP_WIDTH" determines how many clock cycles a bit time may be lengthened or shortened in order to achieve re-synchronization. If this is defined, "CAN_TIME_SEGMENT2" may not be defined and will be set automatically by the driver.

9 - CAN_STOP_IN_WAIT_MODE:

If set to "1", the MSCAN hardware will enter the low power sleep mode if it detects that the central processing unit (CPU) is in a wait state. If set to "0", the sleep mode is disabled.

10 - CAN_LOOP_BACK:

This is self-test mode that enables a chip to internally feed transmitted messages back to its receiver. When set to "1", the loop back mode is enabled.

11 - CAN_WAKE_UP_MODE:

This can be set to prevent the MSCAN driver from waking up from sleep mode due to noise on the bus. When set to "1", a continuous, dominant pulse on the bus is required to wake up from sleep mode. When set to "0", any recessive to dominant edge will cause a wake up. This means that any voltage jump on the bus could be read as a wake up call.

12 - CAN_CLOCK_SOURCE:

This defines whether the internal DSP bus clock is used for CAN bit timing, or whether the timing is determined directly from the oscillator. If set to "0", the oscillator is defined as the CAN clock.

13 & 14 - CAN_CUSTOM_FILTER_CODE &
CAN_CUSTOM_FILTER_MASK:

These two settings are used to define custom message filtering settings. If they are not defined, all message filtering is set when the message buffers are opened. The filter code describes the actual string of numbers in the filter. The filter mask determines which parts of the identifier can be ignored.

15 - CAN_RECEIVE_ID_QUEUE_SIZE:

This determines the size of the message buffer used for received messages. Once this buffer is full, new messages will start overwriting any messages already in the queue.

16 - CAN_RAW_CALLBACK:

This defines the ISR (Interrupt Service Routine) called when a message is received to the queue. The receive ISR is a function which will most likely read the message and store any pertinent data.

MSCAN FUNCTIONS –

Five functions are provided for use in the application code. The "open" function opens a specified CAN identifier for writing or reading. This identifier is then allocated a buffer space and ready to accept data. The "close" statement is used to close any open identifier in order to free up the allocated buffer space.

The “read” statement returns the data portion of the message specified by the associated read identifier. The “write” statement places data into either one of the buffers specified in Queued mode, or directly into one of the three MSCAN transmit buffers.

The “ioctl” statement is used to either set a particular CAN mode or retrieve a status from the CAN hardware. The three modes that can be set are reset, sleep, and wake up. The status messages that can be returned are:

CAN_SYNCHORNIZED – the device is synchronized to a bus

CAN_SLEEP – the device is in sleep mode

CAN_WAKEUP – the device was in sleep mode and has woken up due to bus activity

CAN_RX_WARN – receiver error count exceeds 96

CAN_TX_WARN – transmitter error count exceeds 96

CAN_RX_ERR – receiver error counter exceeds 127 and the device has entered the receiver error passive state

CAN_TX_ERR – transmit error counter exceeds 127 and the device has entered the transmitter error passive state

CAN_BUSOFF – transmit error exceeds 255, CAN device is in bus off state

CAN_OVERRUN – a data overrun has occurred (both MSCAN receive buffers are full and another message was attempted to be read)

CAN_RX_FULL – the receive buffer is full (Queued buffer)

CANID_EMPTY – the specified message buffer is empty

CANID_FULL – the specified message buffer is full

CANID_OVERFLOW – messages are being overwritten in the specified buffer

MSCAN and the Expanded System

The ROV that the expanded system must control is laid out in the following section. The target is a work class vehicle capable of depths of 10,000 fsw (feet of seawater). Components that cannot withstand the pressures at these depths (4,610 psi) must be contained in a sealed, one atmosphere housing. Electronic components that can withstand these pressures can be placed in thinner walled housings that are filled with non-conducting (dielectric) oil and pressure compensated to prevent water incursion. The controller board described for the basic system in Chapter 5 has been designed to take these pressures. The only component that is susceptible to the high pressures is the crystal oscillator. This item can be potted in a small housing using epoxy and the entire board mat be placed in an oil-filled housing.

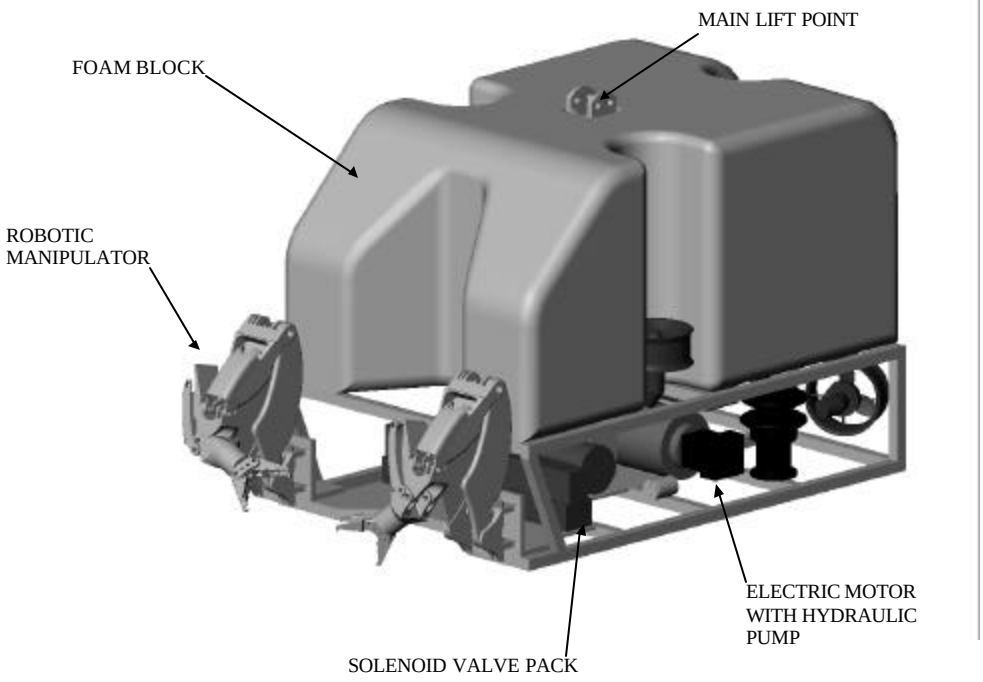


Figure 9.3: ROV with Expanded System, Port Side View

The vehicle can be seen in Figures 9.3 through 9.6. The major items on the system are as follows:

Flotation (Foam) block - provides buoyancy to the system

Aluminum frame - the structure upon which the vehicle is built

(2) Robotic manipulators - used for retrieving and operating items/tools

(2) Solenoid or digital valve packs - these “on/off” valves are used to control the manipulators plus any mission specific equipment; one controller card is required per pack

Electric motor with hydraulic pump - provides hydraulic power to the system

Vehicle power can - contains power supplies, transformers and isolation equipment to supply power to the system (except main motor), relays to actuate

higher power items such as lights, and fiber optic equipment for converting telemetry signals from optics to electrical; one controller card required

(2) Hydraulic reservoirs - contain the hydraulic fluid and provide a pressure compensation system due to an internal spring contained in the flexible, rubber bladder

(5) Thrusters - provide the force to maneuver the vehicle

Umbilical termination can - where the main umbilical (or tether) is splayed out into individual wires.

Transformer can - contains the main power transformer for converting the 3000 volts AC run down the umbilical to the 480 volts required by the electric motor.

Contactor can - provides a means of soft starting the electric motor in case of a vehicle power down

Proportional valve pack - provides proportional control for thrusters as well as any mission specific tooling; two controller cards required

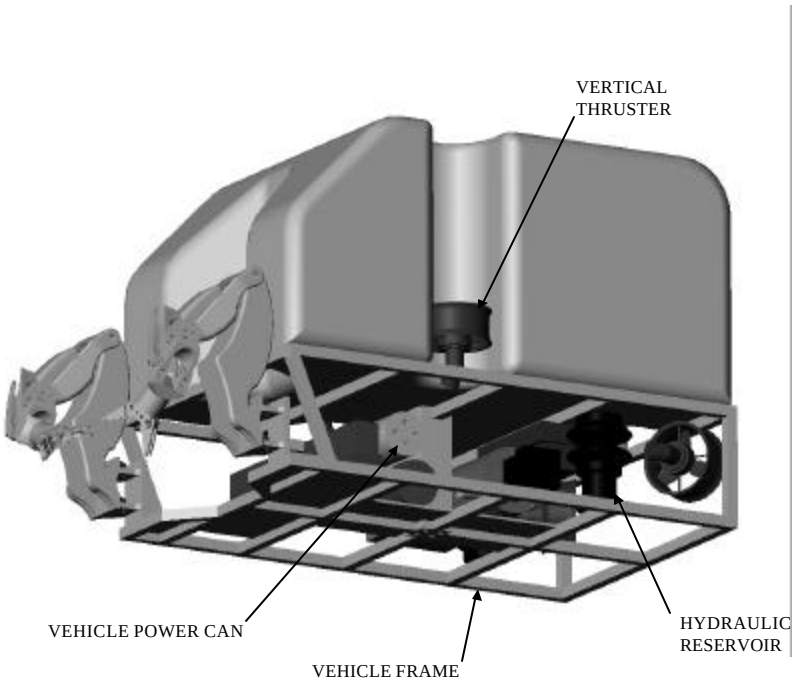


Figure 9.4: ROV with Expanded System, Port Side, Bottom View

The valve packs, power can, and contactor can each contain their own controller boards much like the valve pack described in Chapter 5. The robotic manipulators have up to seven functions each requiring seven three position valves with two digital signals for each valve. The solenoid valve packs must be able to support one manipulator each plus have spare functions for use with tooling and camera pan and tilt units. A ten station valve pack would be suitable requiring 20 digital I/O signals to control it. The DSP56F805 can manage up to 22 digital I/O signals so one controller card per valve pack would be sufficient.

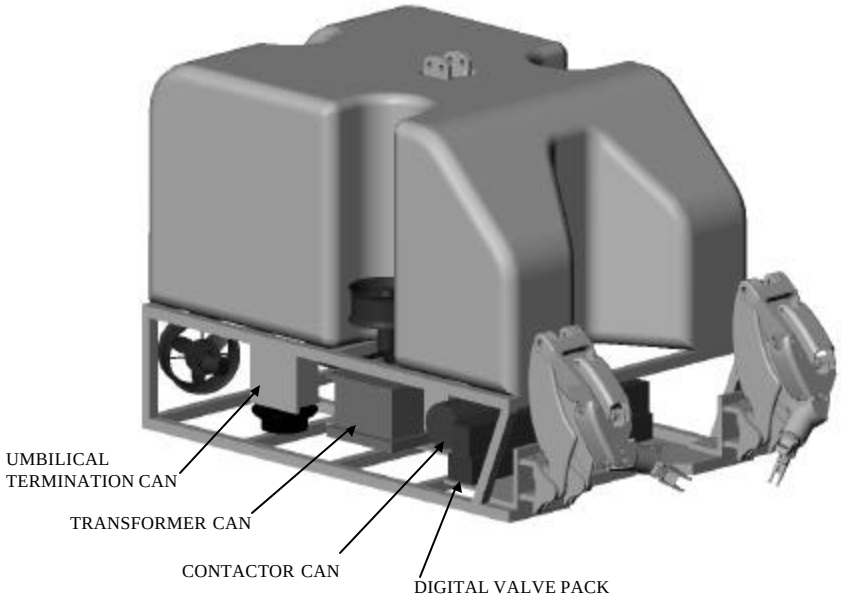


Figure 9.5: ROV with Expanded System, Starboard Side View

The proportional valve pack needs to run five thrusters plus spare functions for tooling. Each controller card can run up to 4 analog channels so an eight function proportional pack (5 thrusters plus three spare) would require two controller cards. All valve packs would be oil-filled housings.

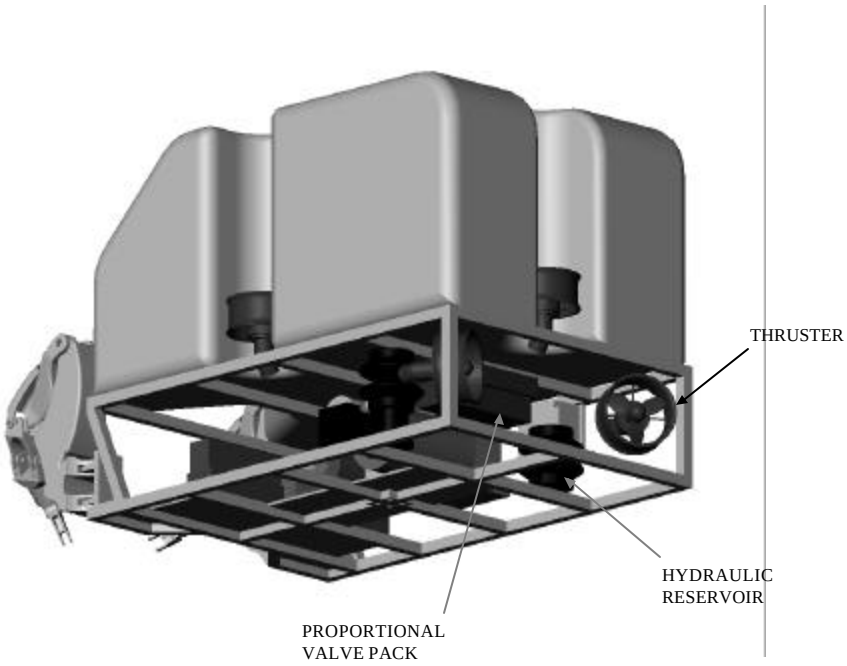


Figure 9.6: ROV with Expanded System, Rear, Bottom View

The vehicle power can would need to be a sealed, one atmosphere housing. The fiber optic converters, relays, and capacitors are not able to withstand the ambient pressures. One controller card can be situated here to provide a communications link to the surface via a serial (RS-232 or 485) link that is converted to fiber optic. This controller card can also be responsible for controlling dimmer functions on lights by way of the four DAC (digital to analog converter) signals.

The entire vehicle system is connected via the common CAN bus as depicted in Figure 9.1. Instead of an EVM (evaluation modules) at each node there is a controller board. If an additional valve pack needs to be added to the system, then it just needs to be teed into the bus. The only requirements are that it must follow the same identifier rules as the existing control system and it must adhere to the CAN protocol. Given that the DSP56F800 series controllers have onboard digital and analog I/O, pulse width modulation modules, and support serial communication (RS-232), there are few pieces of equipment that the controller will not support.

Conclusion:

The Control Area Network protocol provides an easy method to create an expanded system based on the torque tool control system described earlier. The MSCAN drivers are provided in a format similar to the code already written for the existing control system. The drivers also provide a default setting that allows the designer to concentrate on the integration of the various components and ordering of message priorities rather than the details of making the CAN protocol work properly.

The theoretical layout of the ROV shows how the CAN network system simplifies the design process. In ROV designs with card racks and limited

expansion space, the engineer must also concentrate on including space for possible future components. The use of a networked vehicle eliminates this concern. Future components can be added on as new nodes with no software modifications required.

Chapter 10
Conclusion

The purpose of this research was to develop a basic control system for use on subsea, ROV (Remotely Operated Vehicle) tooling that can be expanded to control a full, work-class ROV. This was done by selecting an off the shelf microcontroller that supported a communication protocol with expansion properties. The Motorola DSP56F80X series of microcontrollers was selected because it provides a fast (80MHz) central processing unit (CPU) with onboard I/O capabilities (digital and analog), RS-232 communications, SPI (serial peripheral interface), PWM (pulse width modulation), and CAN (Control Area Network).

An extensive review of current ROV technology revealed that the majority of ROV systems in existence use a PC-based control system. The vehicle side typically contains an Intel (or comparable) processor incorporated onto an industrial bus such as VME. The topside computer is often a standard desktop computer or a rack mount derivative. The vehicle control hardware of these systems require large, one atmosphere, sealed housings to protect the vehicle electronics. The baseline control system designed in this thesis improves upon this housing problem by the basing itself upon a microcontroller that was incorporated into an application specific single board control card. This single board controller has been designed in such a way that it may be housed in a smaller, oil-filled container subject to ambient pressures. The result is a small footprint, lightweight control system.

The baseline system was designed to control an ROV operated, rotary actuator tool or torque tool. The selection of this particular tool provided a simple foundation for the baseline system while having extensive enough requirements to be representative of the expanded system. The baseline system incorporated I/O

(both digital and analog) as well as serial communication. It also presented a need for a user friendly graphical user interface (GUI) which was met through the use of the LabView software. The final product resulted in a single, small footprint unit containing the valves, manifold, and electronics. This system can be easily incorporated into any larger control system that uses serial communications or the CAN protocol.

The method of expansion contributed to the choice of the Motorola DSP because of its support for the Bosch Control Area Network. CAN provides a low level communication protocol that has multiple methods of error checking and high bus speeds. These attributes help explain the success of the protocol in automotive control systems such as anti-lock brakes where reliability is the principle issue.

The Motorola MSCAN drivers provide the higher layer protocol and support software. This package, along with the Software Development Kit (SDK), provides a user friendly environment that can lead to quick product development. After initial development, the default settings may be modified to create a more efficient system.

There are a number of communication protocols available that provide excellent networking capability as well as extensive error checking. The Universal Serial Bus (USB), Ethernet, and TCP/IP were seen as other possible options. USB is known for the "plug & play" attribute that allows the user to simply plug in new components without having to go through complicated jumper settings or software driver installations. Ethernet and TCP/IP are the two most popular protocols used in network systems such as LANs, WANs, and the Internet. Both provide the ability to easily add network nodes and communicate with high reliability. However, none of these methods match the simplicity of the CAN model's broadcast method along with the reliability that results from the five methods of error checking.

ROVs are high noise environments requiring reliable control systems. Because of confined electronics housings, power cables are often run in close proximity to signal wires. Electric motors, hydraulic pumps, and operation in salt air environment also add to the list of electrical engineering obstacles. The Control Area Network was designed for and has been proven to be reliable on automotive control systems. These systems are subject to the wear and tear an automobile must withstand and are still reliable enough to control systems such as anti-lock brakes. While the failure of an ROV won't result in an injury (or possible death) of a person, the money and time involved in offshore industry and research requires a robust system.

The development of this baseline system lays the groundwork for further system design. While the creation of an expanded system will require more funding than this project (MSCAN alone costs $5000), this development opens the door to greater opportunity. When an application arises that requires a control system, the basics have already been done cutting the time to completion dramatically.

Appendix A

TryGPIO

C Code:

```
/*          FILE:     main.c    */
/*          PROJECT:          TryGPIO.mcp       */

#include "port.h"
#include "gpio.h"
#include "bsp.h"

/* File descriptor for LED driver */
static UWord16 LedFD;

/*****************************************************************************/
/*          This function is called upon reception of an interrupt                                    */

static void ButtonA_ISR(void)
{

   /* Toggle (change) state of the green LED */
    ioctl(PortB, GPIO_TOGGLE, gpioPin(B,0));

    /*reset interrupt*/
    ioctl(PortD, GPIO_CLEAR_INTERRUPT_PEND_REGISTER, gpioPin(D,1));

}

/*****************************************************************************/

int PortB;
int PortD;

void main (void)
{


          int value=0;

          PortB = open(BSP_DEVICE_NAME_GPIO_B, NULL);          //initialize Port B

          PortD = open(BSP_DEVICE_NAME_GPIO_D, NULL);          //initialize Port D

          ioctl(PortB, GPIO_SETAS_GPIO, gpioPin(B,0));        // Set Port B, pin 0 as a general
                                                                    purpose I/O

          ioctl(PortD, GPIO_SETAS_GPIO, gpioPin(D,1));        // Set Port D, pin 1 as a general
                                                                    purpose I/O

          ioctl(PortB, GPIO_SETAS_OUTPUT, gpioPin(B,0));   // Set Port B, pin 0 as an output
```

```
        ioctl(PortD, GPIO_INTERRUPT_ENABLE, gpioPin(D,1));          // Enable interrupt control
                                                                        on Port D, pin 1

        ioctl(PortD, GPIO_ENABLE_PULLUP, gpioPin(D,1));             // Enable pullup on Port D,
                                                                        pin 1


        /* Turn green LED on */
        ioctl(PortB, GPIO_CLEAR, gpioPin(B,0));       // Turn off LED by clearing Port B, pin0


         /* Install ButtonISR function as an GPIO Port D interrupt service */
        archInstallISR(&((*pArchInterrupts).MpioD), ButtonA_ISR);

        // start loop
        while(1)
        {
                value=ioctl(PortD, GPIO_READ, gpioPin(D,1));        // value is only used for
                                                                        debugging purposes
        }

}
```

```
/*          FILE:     appconfig.h – External RAM          */
/*          PROJECT:          TryGPIO.mcp       */


#ifndef __APPCONFIG_H
#define __APPCONFIG_H

/*****************************************************************************
*
* Include needed SDK components below by changing #undef to #define.
* Refer to ../config/config.h for complete list of all components and
* component default initialization.
*
*****************************************************************************/

#define INCLUDE_BSP          /* BSP support - includes SIM,COP,CORE,PLL,ITCN */


#undef  INCLUDE_3DES         /* 3des library */
#undef  INCLUDE_ADC          /* ADC support */
#undef  INCLUDE_AEC          /* AEC library */
#undef  INCLUDE_BLDC         /* BLDC library */
#undef  INCLUDE_BUTTON       /* Button support */
#undef  INCLUDE_CALLER_ID    /* CallerID library */
#undef  INCLUDE_CAN          /* CAN support */
#undef  INCLUDE_CAS_DETECT   /* CAS_detect library */
#undef  INCLUDE_COP          /* COP support (subset of BSP) */
#undef  INCLUDE_CORE         /* CORE support (subset of BSP) */
#undef  INCLUDE_CPT          /* CPT library */
#undef  INCLUDE_DAC          /* DAC support */
#undef  INCLUDE_DECODER      /* Quadrature Decoder support */
#undef  INCLUDE_DES          /* DES library */
#undef  INCLUDE_DSPFUNC      /* DSP Function library */
#undef  INCLUDE_DTMF_DET     /* DTMF detect library */
#undef  INCLUDE_DTMF_GEN     /* DTMF generation library */
#undef  INCLUDE_FILEIO       /* File I/O support */
#undef  INCLUDE_FLASH        /* Flash support */
#undef  INCLUDE_G165         /* G165 vocoder library */
#undef  INCLUDE_G711         /* G711 vocoder library */
#undef  INCLUDE_G726         /* G726 vocoder library */
#define  INCLUDE_GPIO        /* General Purpose I/O support */
#define  INCLUDE_IO          /* I/O support */
#undef  INCLUDE_ITCN         /* ITCN support (subset of BSP) */
#define  INCLUDE_LED         /* LED support for target board */
#undef  INCLUDE_MCFUNC       /* Motor Control functional library */
#undef  INCLUDE_MEMORY       /* Memory support */
#undef  INCLUDE_PCMASTER     /* PC Master support */
#undef  INCLUDE_PLL          /* PLL support (subset of BSP) */
#undef  INCLUDE_PWM          /* PWM support */
#undef  INCLUDE_QUAD_TIMER   /* Quadrature timer support */
#undef  INCLUDE_SCI          /* SCI support */
```

```
#undef  INCLUDE_SIM          /* SIM support (subset of BSP) */
#undef  INCLUDE_SPI          /* SPI support */
#undef  INCLUDE_SRM          /* Switch Relactance library */
#undef  INCLUDE_STACK_CHECK   /* Stack utilization routines */
#undef  INCLUDE_SWITCH       /* Switch support */
#undef  INCLUDE_TIMER        /* Timer support */
#undef  INCLUDE_VAD          /* VAD library */
#undef  INCLUDE_V8BIS        /* V8bis library */
#undef  INCLUDE_V22          /* V22 library */
#undef  INCLUDE_V42BIS       /* V42bis library */



/*****************************************************************************
*
* Overwrite default component initializations from config/config.h
* using #defines here
*
*****************************************************************************/
#define GPR_INT_PRIORITY_20 1 /* Setup MpioD ISR priority */

#endif
```

Appendix B

TryREADOUT

C Code:

```
/*      FILE:     main.c    */
/*      PROJECT:          TryREADOUT.mcp          */


#include "port.h"
#include "gpio.h"
#include "bsp.h"


int PortB;
int PortD;


void main (void)
{

        int n=0;
        int ones=3,
        tens=2,
        huns=1;

        // open Ports B & D
        PortB = open(BSP_DEVICE_NAME_GPIO_B, NULL);
        PortD = open(BSP_DEVICE_NAME_GPIO_D, NULL);


        // Initialize Port B & D as outputs
        for (n=0;n<8;n++)
        {
                        ioctl(PortB, GPIO_SETAS_GPIO, gpioPin(B,n));
                        ioctl(PortB, GPIO_SETAS_OUTPUT, gpioPin(B,n));
        }

        for (n=0;n<8;n++)
        {
                        ioctl(PortD, GPIO_SETAS_GPIO, gpioPin(D,n));
                        ioctl(PortD, GPIO_SETAS_OUTPUT, gpioPin(D,n));
        }


        // Output to led display
        if(ones&1)
        ioctl(PortB, GPIO_SET, gpioPin(B,0));

        if(ones&2)
        ioctl(PortB, GPIO_SET, gpioPin(B,1));

        if(ones&4)
```

```
        ioctl(PortB, GPIO_SET, gpioPin(B,2));

        if(ones&8)
        ioctl(PortB, GPIO_SET, gpioPin(B,3));

        if(tens&1)
        ioctl(PortB, GPIO_SET, gpioPin(B,4));

        if(tens&2)
        ioctl(PortB, GPIO_SET, gpioPin(B,5));

        if(tens&4)
        ioctl(PortB, GPIO_SET, gpioPin(B,6));

        if(tens&8)
        ioctl(PortB, GPIO_SET, gpioPin(B,7));

        if(huns&1)
        ioctl(PortD, GPIO_SET, gpioPin(D,0));

        if(huns&2)
        ioctl(PortD, GPIO_SET, gpioPin(D,1));

        if(huns&4)
        ioctl(PortD, GPIO_SET, gpioPin(D,2));

        if(huns&8)
        ioctl(PortD, GPIO_SET, gpioPin(D,3));



        /* sit in loop  */
        while(1)
        {

        }

}
```

```
/*          FILE:     appconfig.h – External RAM          */
/*          PROJECT:          TryREADOUT.mcp          */


#ifndef __APPCONFIG_H
#define __APPCONFIG_H

/*****************************************************************************
*
* Include needed SDK components below by changing #undef to #define.
* Refer to ../config/config.h for complete list of all components and
* component default initialization.
*
*****************************************************************************/

#define INCLUDE_BSP         /* BSP support - includes SIM,COP,CORE,PLL,ITCN */


#undef  INCLUDE_3DES        /* 3des library */
#define  INCLUDE_ADC         /* ADC support */
#undef  INCLUDE_AEC         /* AEC library */
#undef  INCLUDE_BLDC        /* BLDC library */
#undef  INCLUDE_BUTTON      /* Button support */
#undef  INCLUDE_CALLER_ID   /* CallerID library */
#undef  INCLUDE_CAN         /* CAN support */
#undef  INCLUDE_CAS_DETECT  /* CAS_detect library */
#undef  INCLUDE_COP         /* COP support (subset of BSP) */
#undef  INCLUDE_CORE        /* CORE support (subset of BSP) */
#undef  INCLUDE_CPT         /* CPT library */
#undef  INCLUDE_DAC         /* DAC support */
#undef  INCLUDE_DECODER     /* Quadrature Decoder support */
#undef  INCLUDE_DES         /* DES library */
#undef  INCLUDE_DSPFUNC     /* DSP Function library */
#undef  INCLUDE_DTMF_DET    /* DTMF detect library */
#undef  INCLUDE_DTMF_GEN    /* DTMF generation library */
#undef  INCLUDE_FILEIO      /* File I/O support */
#undef  INCLUDE_FLASH       /* Flash support */
#undef  INCLUDE_G165        /* G165 vocoder library */
#undef  INCLUDE_G711        /* G711 vocoder library */
#undef  INCLUDE_G726        /* G726 vocoder library */
#define  INCLUDE_GPIO        /* General Purpose I/O support */
#define  INCLUDE_IO          /* I/O support */
#undef  INCLUDE_ITCN        /* ITCN support (subset of BSP) */
#define  INCLUDE_LED         /* LED support for target board */
#undef  INCLUDE_MCFUNC      /* Motor Control functional library */
#undef  INCLUDE_MEMORY      /* Memory support */
#undef  INCLUDE_PCMASTER    /* PC Master support */
#undef  INCLUDE_PLL         /* PLL support (subset of BSP) */
#undef  INCLUDE_PWM         /* PWM support */
#undef  INCLUDE_QUAD_TIMER  /* Quadrature timer support */
#undef  INCLUDE_SCI         /* SCI support */
```

```
#undef  INCLUDE_SIM          /* SIM support (subset of BSP) */
#undef  INCLUDE_SPI          /* SPI support */
#undef  INCLUDE_SRM          /* Switch Relactance library */
#undef  INCLUDE_STACK_CHECK   /* Stack utilization routines */
#undef  INCLUDE_SWITCH       /* Switch support */
#undef  INCLUDE_TIMER        /* Timer support */
#undef  INCLUDE_VAD          /* VAD library */
#undef  INCLUDE_V8BIS        /* V8bis library */
#undef  INCLUDE_V22          /* V22 library */
#undef  INCLUDE_V42BIS       /* V42bis library */



/*****************************************************************************
*
* Overwrite default component initializations from config/config.h
* using #defines here
*
*****************************************************************************/
//#define GPR_INT_PRIORITY_20 1 /* Setup MpioD ISR priority */

#endif
```

Appendix C

Serial Test

C Code:

```
/*        FILE:     main.c    */
/*        PROJECT:          Serial test.mcp     */


#include "port.h"
#include "sci.h"
#include "io.h"
#include "bsp.h"
#include "assert.h"

// CallBack function prototypes
void sciRxCallBack(void);
void sciTxCallBack(void);
void sciExceptionCallBack(void);

int SCI0, count;
UWord16 DataR;

/*************************************************************************
* SCI Receive CallBack Routine
*
* Description: This function is called when the SCI driver has received
* the number of characters specified by the read length.
*************************************************************************/

void sciRxCallBack(void)
{
        read( SCI0, &DataR, sizeof(DataR) );    // Read a character
        write(SCI0, "Hello", sizeof("Hello") );    // Send it back to the pc (echo)

}

/*************************************************************************
* SCI Transmit CallBack Routine
*
* Description: This function is called when the SCI driver has sent all
* data in its transmit buffer.
*************************************************************************/

void sciTxCallBack(void)

{
        /* Add code for Transmit handling */
        asm(nop);

}

/*************************************************************************
```

```
* SCI Exception CallBack Routine
*
* Description: This function is called when the SCI driver has detected
* an exception.
*************************************************************************/

void sciExceptionCallBack(void)
{
        /* Add code for exception handling */
        asm(debug);

}


void main (void)
{

        UWord16 SciReadLength;
        sci_sConfig SciConfig;

        SciConfig.SciCntl   = SCI_CNTL_WORD_8BIT | SCI_CNTL_PARITY_NONE;
        SciConfig.SciHiBit = SCI_HIBIT_0;
        SciConfig.BaudRate = SCI_BAUD_9600;

        SCI0 = open(BSP_DEVICE_NAME_SCI_0, O_RDWR | O_NONBLOCK, &SciConfig);

        if (SCI0 == -1)
        {
                assert(!" Open /sci0 device failed.");

        }

        /* Set the data format for 8-bit characters
                and Clear the Read and Write buffers */
        ioctl(SCI0, SCI_DATAFORMAT_EIGHTBITCHARS, NULL);

        /* Set the Receive, Transmit, and Exception Callback functions */
        ioctl(SCI0, SCI_CALLBACK_RX, sciRxCallBack);
        ioctl(SCI0, SCI_CALLBACK_TX, sciTxCallBack);
        ioctl(SCI0, SCI_CALLBACK_EXCEPTION, sciExceptionCallBack);

        /* The SCI Rx CallBack function will be called by the SCI driver after
                one character is received by setting the read length to 1. */
        SciReadLength = 1;
        ioctl(SCI0, SCI_SET_READ_LENGTH, &SciReadLength);

        /* Wait for data to be received */
        /* Use HyperTerminal to send characters, "Hello" will be echoed back
                by the Receive CallBack function */
        while (1)
        {
```

```
                count++;
        }

        return;

}
```

```
/*          FILE:     appconfig.h – External RAM          */
/*          PROJECT:          Serial test.mcp     */


#ifndef __APPCONFIG_H
#define __APPCONFIG_H

/*************************************************************************
*
* Include needed SDK components below by changing #undef to #define.
* Refer to ../config/config.h for complete list of all components and
* component default initialization.
*
*************************************************************************/

#define INCLUDE_BSP          /* BSP support - includes SIM,COP,CORE,PLL,ITCN */


#undef  INCLUDE_3DES         /* 3des library */
#undef  INCLUDE_ADC          /* ADC support */
#undef  INCLUDE_AEC          /* AEC library */
#undef  INCLUDE_BLDC         /* BLDC library */
#undef  INCLUDE_BUTTON       /* Button support */
#undef  INCLUDE_CALLER_ID    /* CallerID library */
#undef  INCLUDE_CAN          /* CAN support */
#undef  INCLUDE_CAS_DETECT   /* CAS_detect library */
#undef  INCLUDE_COP          /* COP support (subset of BSP) */
#undef  INCLUDE_CORE         /* CORE support (subset of BSP) */
#undef  INCLUDE_CPT          /* CPT library */
#undef  INCLUDE_DAC          /* DAC support */
#undef  INCLUDE_DECODER      /* Quadrature Decoder support */
#undef  INCLUDE_DES          /* DES library */
#undef  INCLUDE_DSPFUNC      /* DSP Function library */
#undef  INCLUDE_DTMF_DET     /* DTMF detect library */
#undef  INCLUDE_DTMF_GEN     /* DTMF generation library */
#undef  INCLUDE_FILEIO       /* File I/O support */
#undef  INCLUDE_FLASH        /* Flash support */
#undef  INCLUDE_G165         /* G165 vocoder library */
#undef  INCLUDE_G711         /* G711 vocoder library */
#undef  INCLUDE_G726         /* G726 vocoder library */
#undef  INCLUDE_GPIO         /* General Purpose I/O support */
#define  INCLUDE_IO          /* I/O support */
#undef  INCLUDE_ITCN         /* ITCN support (subset of BSP) */
#undef  INCLUDE_LED          /* LED support for target board */
#undef  INCLUDE_MCFUNC       /* Motor Control functional library */
#undef  INCLUDE_MEMORY       /* Memory support */
#undef  INCLUDE_PCMASTER     /* PC Master support */
#undef  INCLUDE_PLL          /* PLL support (subset of BSP) */
#undef  INCLUDE_PWM          /* PWM support */
#undef  INCLUDE_QUAD_TIMER   /* Quadrature timer support */
#define  INCLUDE_SCI         /* SCI support */
```

```
#undef  INCLUDE_SIM          /* SIM support (subset of BSP) */
#undef  INCLUDE_SPI          /* SPI support */
#undef  INCLUDE_SRM          /* Switch Relactance library */
#undef  INCLUDE_STACK_CHECK   /* Stack utilization routines */
#undef  INCLUDE_SWITCH       /* Switch support */
#undef  INCLUDE_TIMER        /* Timer support */
#undef  INCLUDE_VAD          /* VAD library */
#undef  INCLUDE_V8BIS        /* V8bis library */
#undef  INCLUDE_V22          /* V22 library */
#undef  INCLUDE_V42BIS       /* V42bis library */



/*******************************************************************************
*
* Overwrite default component initializations from config/config.h
* using #defines here
*
*******************************************************************************/


#endif
```

Appendix D

LabViewGPIO

C Code:

```
/*      FILE:     main.c    */
/*      PROJECT:        LabViewGPIO.mcp         */

#include "port.h"
#include "gpio.h"
#include "bsp.h"
#include "sci.h"
#include "io.h"
#include "assert.h"
#include "time.h"
#include <string.h>
#include <stdio.h>


static void COUNTRECEIVED(void);
static void TURNSCOUNT(void);


/*********************************************************
* Skeleton C main program for use with Embedded SDK
*********************************************************/


int SCI0;
int count=0x30;
int prevcount=0x00;
char digitones[2]="0";
char digittens[2]="0";
char goingout[2] ="00";
int PortB;
int PortD;

/*********************************************************************/
static void TURNSCOUNT()
{
        int temp1=*digittens;

        prevcount=count;

        count++;

        if(temp1==(0x39) & count==(0x39+1))
        {
                count=0x30;

                *digitones=count;

                temp1=0x30;
```

```
                *digittens=temp1;
        }

        else if(count==(0x39+1))
        {
                count=0x30;

                *digitones=count;

                temp1++;

                *digittens=temp1;

                //count=0x30;
        }

        else
        {
                *digitones=count;
        }


}



/*****************************************************************************/
static void COUNTRECEIVED(void)
{

        //      call function to assemble count string
        TURNSCOUNT();

        //      construct outgoing string
        strcpy(goingout, digittens);
        strcat(goingout, digitones);


   /* Toggle (change) state of the red LED */
    ioctl(PortB, GPIO_TOGGLE, gpioPin(B,0));

    //      write string to serial port
    write(SCI0, &goingout, sizeof(goingout));



}
```

```
/*****************************************************************************/


void main (void)
{
	/*
		This program serves as a quick start guide to
		writing either C or ASM programs using the
		Embedded SDK.  Modify it at will
	*/

	int value;
	struct timespec QuartSecond = {0, 250000000};		//define pause of 1/4 second
	sci_sConfig SciConfig;


	SciConfig.SciCntl   = SCI_CNTL_WORD_8BIT | SCI_CNTL_PARITY_NONE;
	SciConfig.SciHiBit = SCI_HIBIT_0;
	SciConfig.BaudRate = SCI_BAUD_9600;

	SCI0 = open(BSP_DEVICE_NAME_SCI_0, O_RDWR | O_NONBLOCK, &SciConfig);

	if (SCI0 == -1)
	{
		assert(!" Open /sci0 device failed.");

	}

	/* Set the data format for 8-bit characters
		and Clear the Read and Write buffers */
	ioctl(SCI0, SCI_DATAFORMAT_EIGHTBITCHARS, NULL);


	//	Initialize gpio ports b and d
	PortD = open(BSP_DEVICE_NAME_GPIO_D, NULL);

	PortB = open(BSP_DEVICE_NAME_GPIO_B, NULL);


	//	Initialize pins B,0 and D,1
	ioctl(PortB, GPIO_SETAS_GPIO, gpioPin(B,0));

	ioctl(PortD, GPIO_SETAS_GPIO, gpioPin(D,1));

	//	Set Pin B,0 as output
	ioctl(PortB, GPIO_SETAS_OUTPUT, gpioPin(B,0));


	//	Set pin D,1 as input
	ioctl(PortD, GPIO_ENABLE_PULLUP, gpioPin(D,1));
```

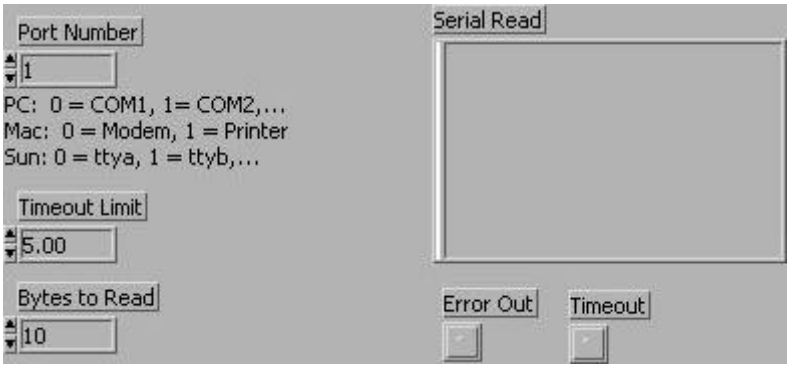
```
        /* Clear B,0 */
        ioctl(PortB, GPIO_CLEAR, gpioPin(B,0));



    /* Install ButtonISR function as an IRQ A interrupt service */
        //archInstallISR(&((*pArchInterrupts).MpioD), COUNTRECEIVED);


        while(1)
        {

                value=ioctl(PortD, GPIO_READ, gpioPin(D,1));

                if(value)
                {
                        COUNTRECEIVED();
                        nanosleep(&QuartSecond, NULL);
                }


        }


}
```

```
/*          FILE:     appconfig.h – External RAM          */
/*          PROJECT:          LabViewGPIO.mcp          */


#ifndef __APPCONFIG_H
#define __APPCONFIG_H

/*****************************************************************************
*
* Include needed SDK components below by changing #undef to #define.
* Refer to ../config/config.h for complete list of all components and
* component default initialization.
*
*****************************************************************************/

#define INCLUDE_BSP          /* BSP support - includes SIM,COP,CORE,PLL,ITCN */


#undef  INCLUDE_3DES         /* 3des library */
#undef  INCLUDE_ADC          /* ADC support */
#undef  INCLUDE_AEC          /* AEC library */
#undef  INCLUDE_BLDC         /* BLDC library */
#undef  INCLUDE_BUTTON       /* Button support */
#undef  INCLUDE_CALLER_ID    /* CallerID library */
#undef  INCLUDE_CAN          /* CAN support */
#undef  INCLUDE_CAS_DETECT   /* CAS_detect library */
#undef  INCLUDE_COP          /* COP support (subset of BSP) */
#undef  INCLUDE_CORE         /* CORE support (subset of BSP) */
#undef  INCLUDE_CPT          /* CPT library */
#undef  INCLUDE_DAC          /* DAC support */
#undef  INCLUDE_DECODER      /* Quadrature Decoder support */
#undef  INCLUDE_DES          /* DES library */
#undef  INCLUDE_DSPFUNC      /* DSP Function library */
#undef  INCLUDE_DTMF_DET     /* DTMF detect library */
#undef  INCLUDE_DTMF_GEN     /* DTMF generation library */
#undef  INCLUDE_FILEIO       /* File I/O support */
#undef  INCLUDE_FLASH        /* Flash support */
#undef  INCLUDE_G165         /* G165 vocoder library */
#undef  INCLUDE_G711         /* G711 vocoder library */
#undef  INCLUDE_G726         /* G726 vocoder library */
#define  INCLUDE_GPIO        /* General Purpose I/O support */
#define  INCLUDE_IO          /* I/O support */
#undef  INCLUDE_ITCN         /* ITCN support (subset of BSP) */
#undef  INCLUDE_LED          /* LED support for target board */
#undef  INCLUDE_MCFUNC       /* Motor Control functional library */
#undef  INCLUDE_MEMORY       /* Memory support */
#undef  INCLUDE_PCMASTER     /* PC Master support */
#undef  INCLUDE_PLL          /* PLL support (subset of BSP) */
#undef  INCLUDE_PWM          /* PWM support */
#undef  INCLUDE_QUAD_TIMER   /* Quadrature timer support */
#define  INCLUDE_SCI         /* SCI support */
```

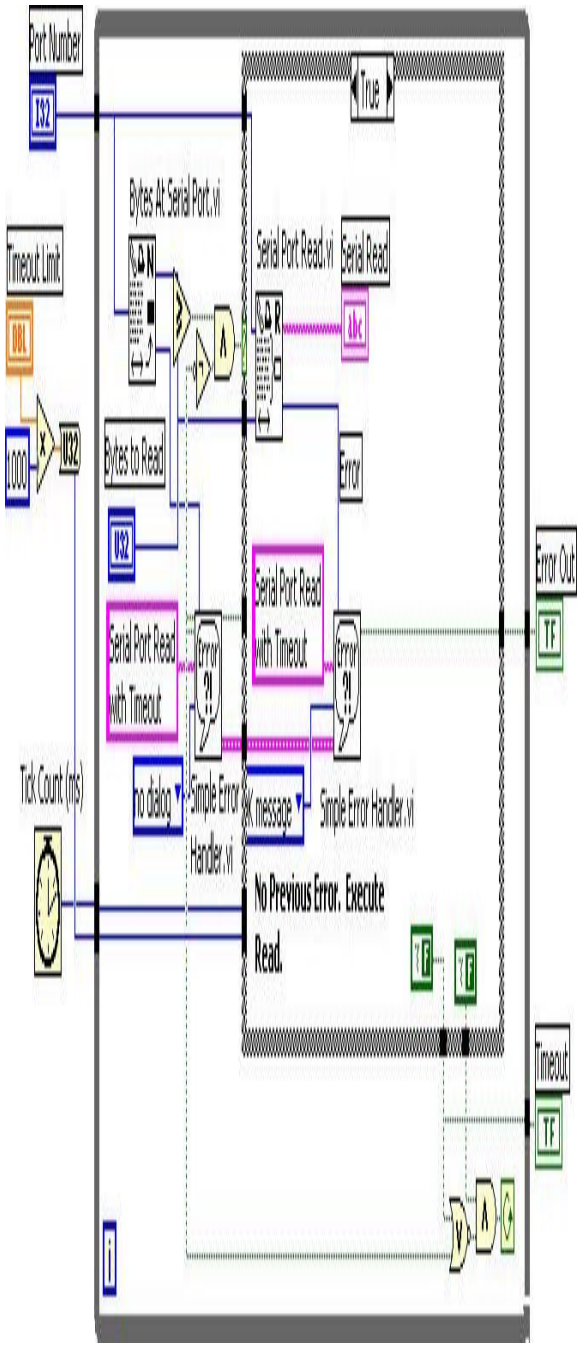
```
#undef  INCLUDE_SIM          /* SIM support (subset of BSP) */
#undef  INCLUDE_SPI          /* SPI support */
#undef  INCLUDE_SRM          /* Switch Relactance library */
#undef  INCLUDE_STACK_CHECK   /* Stack utilization routines */
#undef  INCLUDE_SWITCH       /* Switch support */
#define  INCLUDE_TIMER       /* Timer support */
#undef  INCLUDE_VAD          /* VAD library */
#undef  INCLUDE_V8BIS        /* V8bis library */
#undef  INCLUDE_V22          /* V22 library */
#undef  INCLUDE_V42BIS       /* V42bis library */


/*******************************************************************************
*
* Overwrite default component initializations from config/config.h
* using #defines here
*
*******************************************************************************/
#define GPR_INT_PRIORITY_20 1 /* Setup MpioD ISR priority */

#endif
```

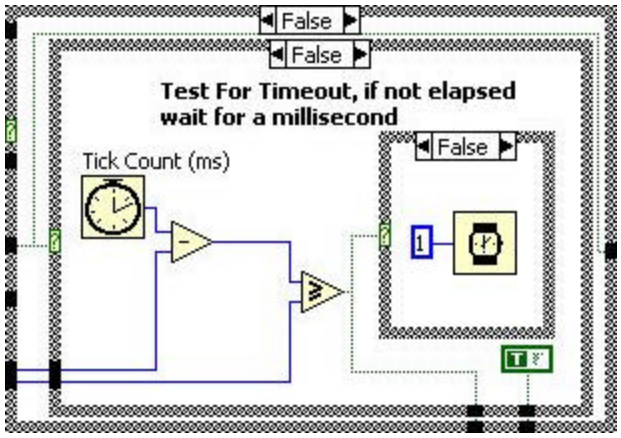
LabView:

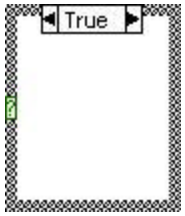
Front Panel

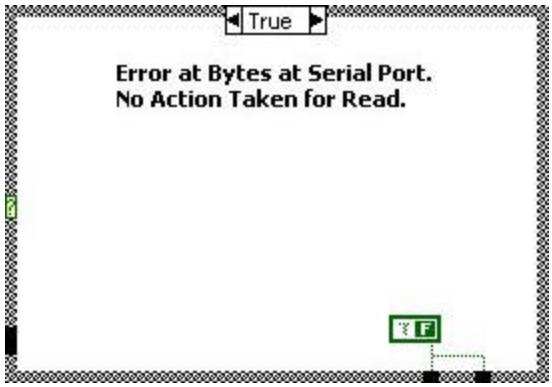


Block Diagram




False
False
Test For Timeout, if not elapsed
wait for a millisecond
Tick Count (ms)
False
1


True


True
Error at Bytes at Serial Port.
No Action Taken for Read.

Appendix E

adctest2

C Code:

```
/*          FILE:     adctest2.c          */
/*          PROJECT: adctest2.mcp     */

#include "port.h"
#include "arch.h"
#include "io.h"

#include "string.h"

#include "fcntl.h"
#include "assert.h"
#include "adc.h"
#include "led.h"
#include "periph.h"
#include "gpio.h"
#include "types.h"

#include "bsp.h"
#include "sci.h"

int CCFlag;    /* synchronization flag */

void CC_CallBack( adc_eCallbackType type, adc_tSampleMask causedSampleMask );


/**********************          ADC Channel 0 Configuration          ********************/
static const adc_sState sadc1 = {

 /* AnalogChannel      = */  ADC_CHANNEL_0,
 /* NumSamplesPerScan  = */  1,

 /* OffsetRegister     = */  0,
 /* LowLimitRegister   = */  0,
 /* HighLimitRegister  = */  0,
 /* ZeroCrossing       = */  0,

};

/**********************          ADC Channel Structure      **********************/
struct ChannelData
{
   UWord16    handle;
   ssize_t    len;
   Frac16     Buf[8];
};
struct ChannelData  Data1;

/*          Low limit threshold for enabling/disabling LED          */
```

```
static const Frac16 low2Threshold = FRAC16(0.6);


static int LedFD;
static int PortD;

main()
{
   int      i;
   int      NumSend;
   int      NumSendTens;
   int              NumSendOnes;
   int              NumSendHuns;
   int              NumSendThous;

   sci_sConfig SciConfig;
            int SCI0;

            //          Opern ADC port
   Data1.handle  = open(BSP_DEVICE_NAME_ADC_0, 0, &sadc1 );

   /*********************  CONFIG SERIAL  *************************/

            SciConfig.SciCntl   = SCI_CNTL_WORD_8BIT | SCI_CNTL_PARITY_NONE;
            SciConfig.SciHiBit = SCI_HIBIT_0;
            SciConfig.BaudRate = SCI_BAUD_9600;

            SCI0 = open(BSP_DEVICE_NAME_SCI_0, O_RDWR | O_NONBLOCK, &SciConfig);

            if (SCI0 == -1)
            {
                     assert(!" Open /sci0 device failed.");

            }

            /* Set the data format for 8-bit characters
                     and Clear the Read and Write buffers */
            ioctl(SCI0, SCI_DATAFORMAT_EIGHTBITCHARS, NULL);

            /*          CONFIG GPIO      */

#if defined( BSP_DEVICE_NAME_GPIO_D )

   PortD = open( BSP_DEVICE_NAME_GPIO_D, 0);

   ioctl(PortD, GPIO_SETAS_OUTPUT, gpioPin(D, 4) );
   ioctl(PortD, GPIO_SETAS_GPIO, gpioPin(D, 4) );
   ioctl(PortD, GPIO_SET, gpioPin(D, 4) );

#endif /* defined( BSP_DEVICE_NAME_GPIO_D )  */
```

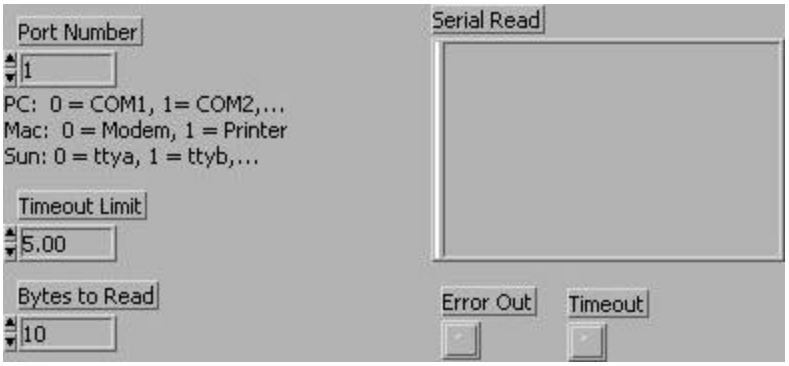
```
   LedFD  = open(BSP_DEVICE_NAME_LED_0,  0);


#if defined( LED_YELLOW )
   ioctl(LedFD,  LED_OFF, LED_YELLOW);
#endif /* defined( LED_YELLOW ) */

   CCFlag = 0;

   //       Start ADC read
   ioctl( Data1.handle, ADC_START, 0 );


            //          Construct string
   while(1)
   {
      Data1.len = read( Data1.handle, Data1.Buf, sizeof(Data1.Buf) );

      if( Data1.len > 0 )
      {

            NumSend=Data1.Buf[0];
            /* Calibrate Data: ADC range 0-32559,theoretical pressure range 0-3000 psi */
            /* 32559/3000 = 10.853 */
            NumSend=NumSend/10.853;

            //NumSendThous=NumSend/1000;
            //NumSendHuns=(NumSend-(NumSendThous*1000))/100;
            //NumSendTens=(NumSend-(NumSendThous*1000)-(NumSendHuns*100))/10;
            //NumSendOnes=(NumSend-(NumSendThous*1000)-(NumSendHuns*100)-
            //          (NumSendTens*10));


      /*************** SEND STRING******************/
            write(SCI0, &NumSend, sizeof(NumSend));

            //          Set LED if ADC read is below threshold
         if( Data1.Buf[0] > low2Threshold )
         {
#if defined( LED_YELLOW )
            ioctl(LedFD,  LED_ON, LED_YELLOW);
#endif /* defined( LED_YELLOW ) */
         }
         else
         {
#if defined( LED_YELLOW )
            ioctl(LedFD,  LED_OFF, LED_YELLOW);
#endif /* defined( LED_YELLOW ) */
         }
         Data1.len = 0;
```

```
      }

                        //          Reset synchro flag and start another ADC read
      if( CCFlag > 0 )
      {
         CCFlag = 0;
         ioctl( Data1.handle, ADC_START, 0 );
      }


   }
}

/*********************FUNCTION CC_CallBack                ***************************/
/*                                                                                  */
/*          This function handles the ADC conversion complete interrupt and         */
/*          increments the syncronization flag to start another read.               */
/*                                                                                  */
/************************************************************************************/
void CC_CallBack( adc_eCallbackType type, adc_tSampleMask causedSampleMask )
{
   CCFlag = 1;
}
```

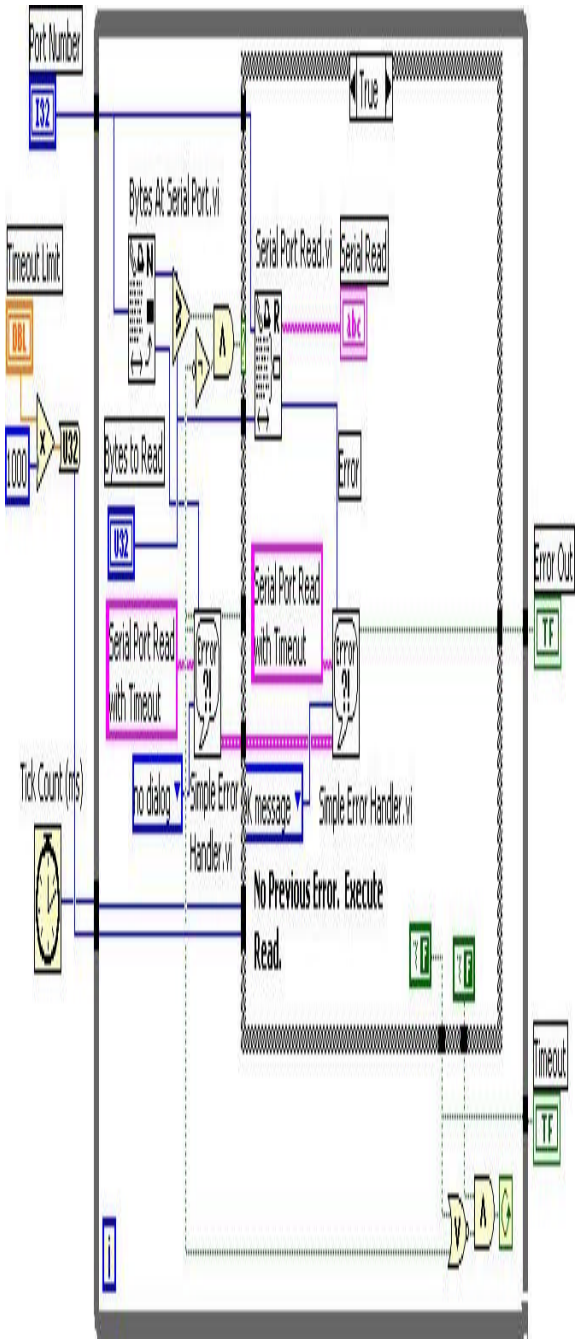
```
/*          FILE:     appconfig.h - External RAM          */
/*          PROJECT: adctest2.mcp     */

#ifndef __APPCONFIG_H
#define __APPCONFIG_H

/* Refer to config/config.h for complete list of all components and
          component default initialization */

/*****************************************************************************
*
* Include needed SDK components
*
*****************************************************************************/

#define INCLUDE_BSP          /* BSP support */

#undef  INCLUDE_CODEC        /* codec driver */
#define INCLUDE_IO          /* I/O support */
#define INCLUDE_LED          /* led support for target board */
#undef  INCLUDE_SPI          /* spi support */
#undef  INCLUDE_TIMER        /* timer support */
#undef  INCLUDE_FLASH        /* flash support */
#define  INCLUDE_SCI         /* SCI support */
#define INCLUDE_ADC          /* ADC support */
#undef  INCLUDE_QUAD_TIMER    /* Quadrature timer support */
#undef  INCLUDE_CAN          /* CAN support */

#define INCLUDE_GPIO

#undef  INCLUDE_MEMORY       /* memory support */
#undef  INCLUDE_DSPFUNC      /* dsp functional library */


/*****************************************************************************
*
* Overwrite default component initialization from config/config.h
*
*****************************************************************************/


/*          Set scan mode for ADC port          */
#define ADC_SCANMODE  ADC_SEQUENTIAL_ONCE

/* include samples */
#define INCLUDE_ADCA_SAMPLE_0

/* user callback */
#define ADC_RAW_CONVERSION_COMPLETE_CALLBACK  CC_CallBack

#endif
```

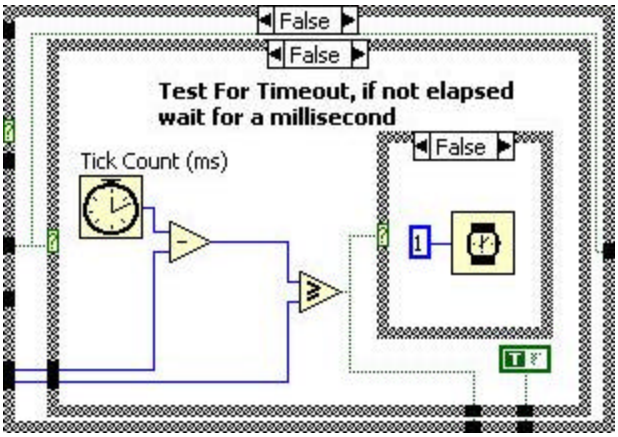
LabView:

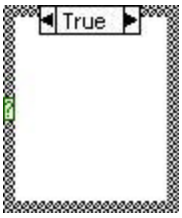
Front Panel

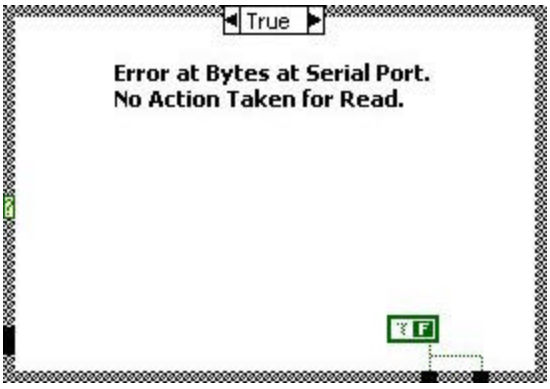


Block Diagram




False
False
Test For Timeout, if not elapsed
wait for a millisecond
Tick Count (ms)
False
1
T


True


True
Error at Bytes at Serial Port.
No Action Taken for Read.
F

Appendix F

TryDAC

C Code:

```
/*          FILE:     TryDAC.c          */
/*          PROJECT: TryDAC.mcp    */


#include "port.h"
#include "arch.h"
#include "stdlib.h"
#include "io.h"
#include "fcntl.h"
#include "dac.h"
#include "dspfunc.h"
#include "time.h"
#include "led.h"
#include "assert.h"



static UWord16   AValues[1];
static int   dacDevice;


/*****************************************************************************
*
* Module: main()
*
* Description:
*   The DAC driver application is designed to test and demonstrate the usage
*   of the DAC driver's API to control and communicate with the DSP56805 EVM
*   target board hardware.
*
*
*
* Returns: None
*
* Arguments: None
*
* Range Issues: None
*
* Special Issues: None
*
*****************************************************************************/
void main(void)
{
          int n=0;


          /* Get handle to DAC device */
          dacDevice = open(BSP_DEVICE_NAME_DAC, NULL);
```

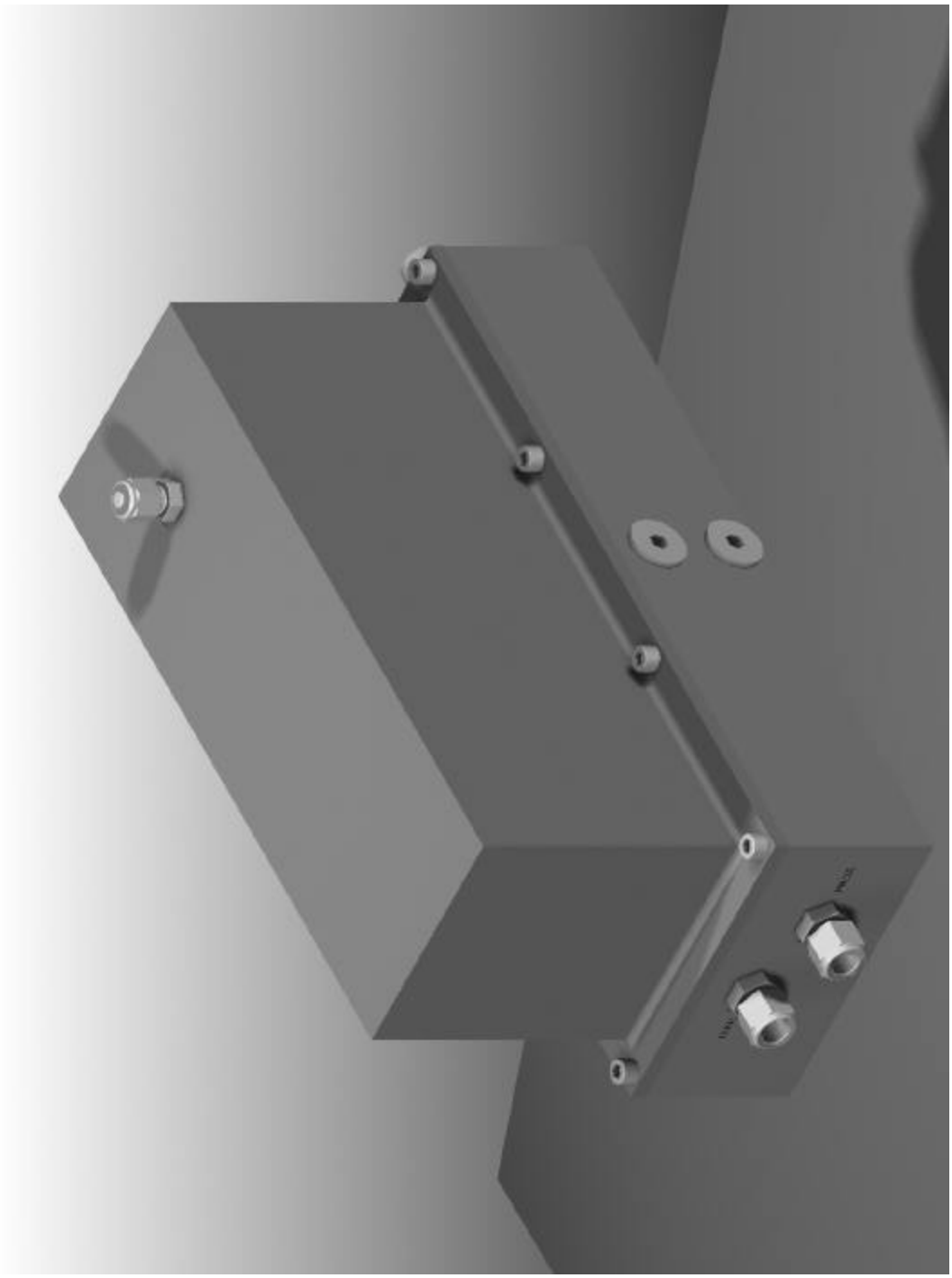
```
        //          Set Value for output
        AValues[0]=65535;

        /* Output value on Channel A */
        ioctl(dacDevice, DAC_SET_CHANNEL_A, NULL);
        ioctl(dacDevice, DAC_WRITE_MODE_UPDATE, NULL);
        write(dacDevice, AValues, sizeof(UWord16));


}
```

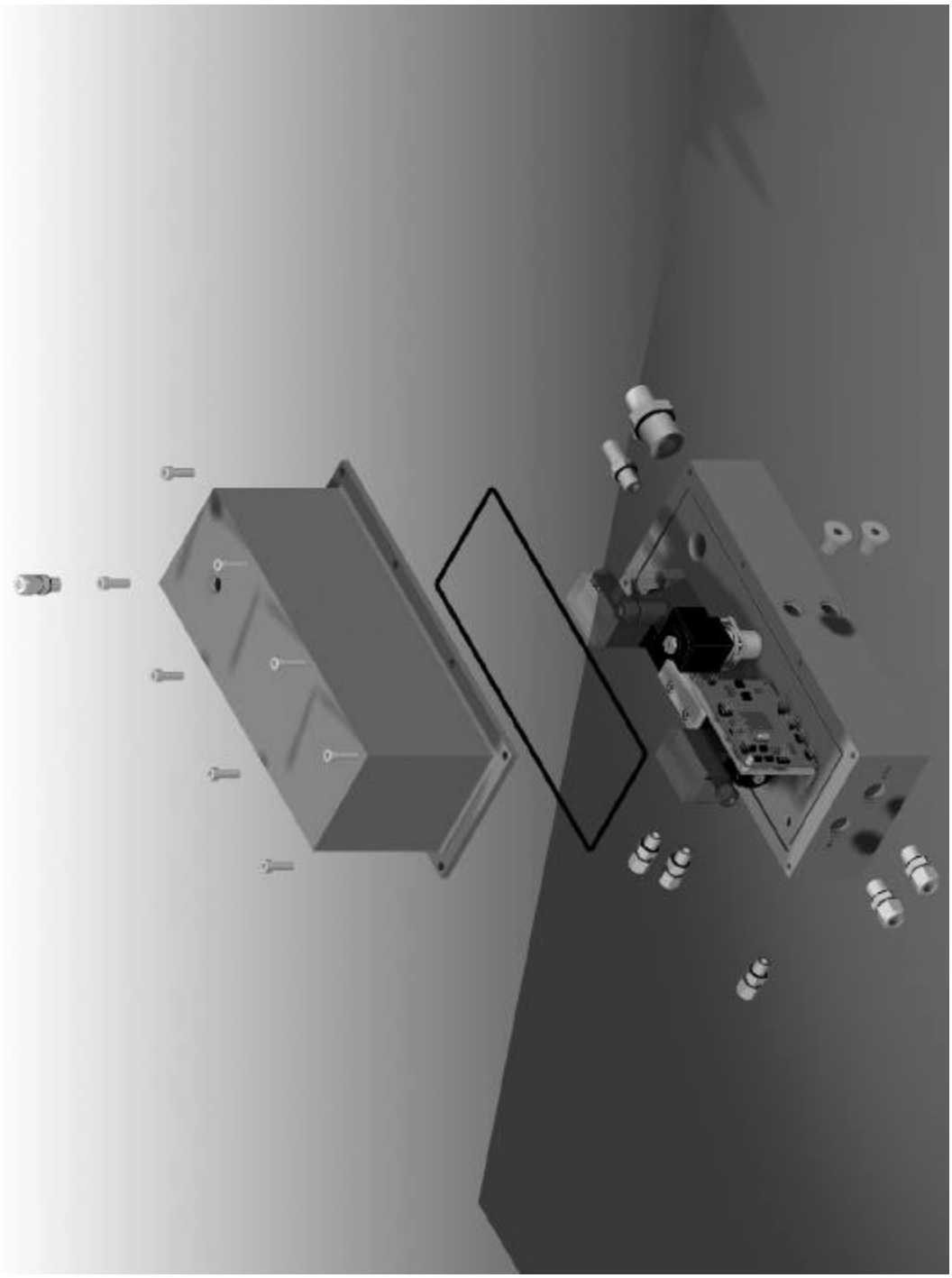
```
/*          FILE:      appconfig.h - External RAM            */
/*          PROJECT: TryDAC.mcp     */

#ifndef __APPCONFIG_H
#define __APPCONFIG_H

#ifdef __cplusplus
extern "C" {
#endif
/*****************************************************************************
*
* Include needed SDK components by changing the #undef to #define
* Refer to config/config.h for complete list of all components and
* component default initialization.
*
*****************************************************************************/

#define INCLUDE_BSP          /* BSP support */

#undef  INCLUDE_CODEC        /* codec driver */
#define  INCLUDE_IO          /* I/O support */
#undef  INCLUDE_SPI          /* spi support */
#define  INCLUDE_TIMER       /* timer support */
#undef  INCLUDE_FLASH        /* flash support */
#undef  INCLUDE_SCI          /* SCI support */
#undef  INCLUDE_ADC          /* ADC support */
//#define  INCLUDE_QUAD_TIMER    /* Quadrature timer support */
#undef  INCLUDE_CAN          /* CAN support */
#undef  INCLUDE_PWM          /* PWM support */
#undef  INCLUDE_DECODER      /* Quadrature Decoder support */
#undef  INCLUDE_FILEIO       /* File I/O support */
#define  INCLUDE_GPIO        /* General Purpose I/O support */
#undef  INCLUDE_BUTTONS      /* Buttons support */
#undef  INCLUDE_PCMASTER     /* PC Master support */
#define  INCLUDE_DAC         /* DAC support */
#define  INCLUDE_LED         /* led support for target board */

#define  INCLUDE_DSPFUNC     /* dsp functional library */
#undef  INCLUDE_MCFUNC       /* mc functional library */
#undef  INCLUDE_BLDC         /* bldc library */
#undef  INCLUDE_MEMORY       /* memory support */

#undef  INCLUDE_STACK_CHECK   /* stack utilization routines */


/* POSIX timers */
//#define INCLUDE_USER_TIMER_C_0  1
//#define INCLUDE_USER_TIMER_C_1  1
//#define INCLUDE_USER_TIMER_C_2  1
```

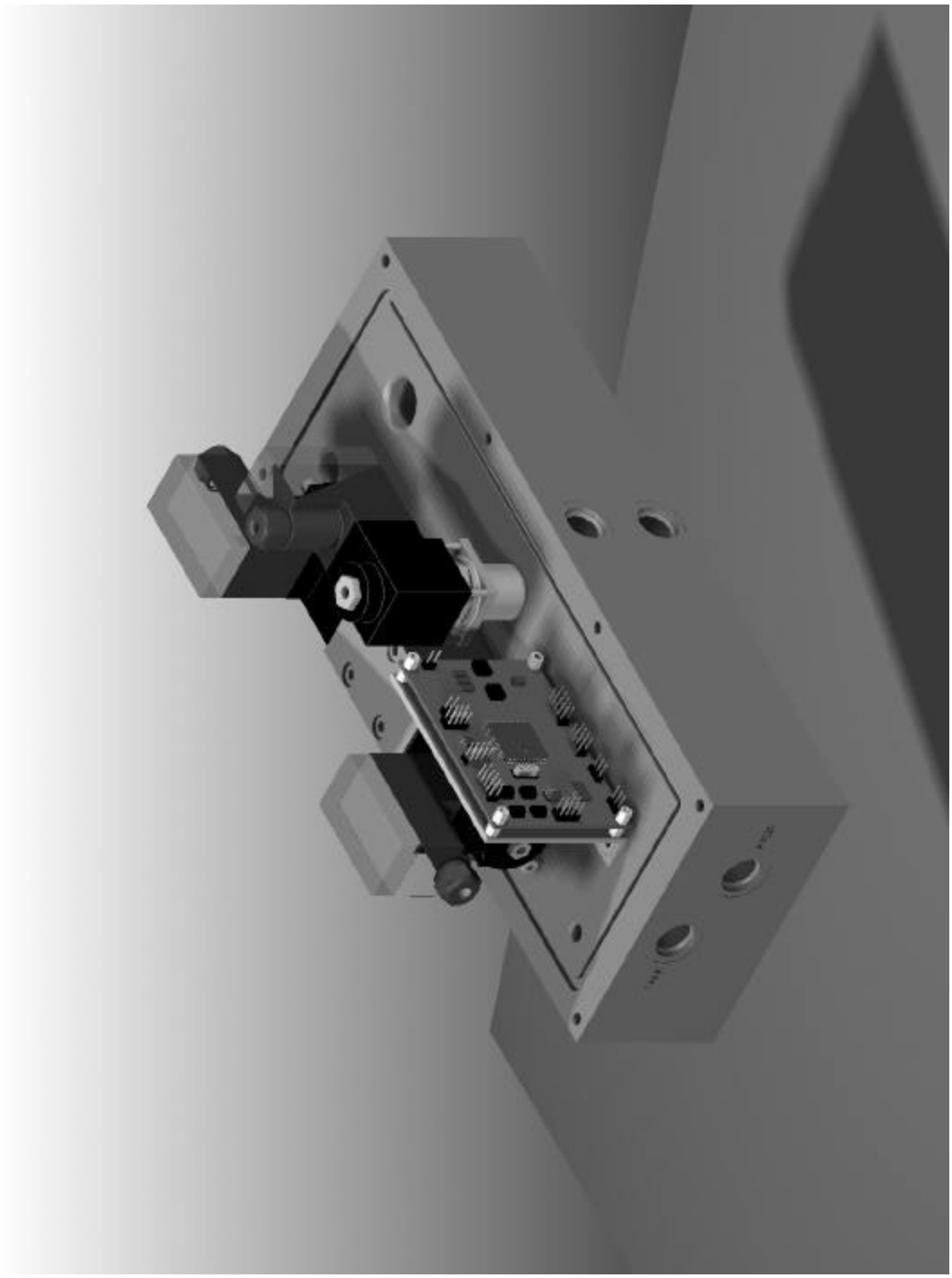
```
/*****************************************************************************
*
* Overwrite default component initialization from config/config.h
*
*****************************************************************************/


#ifdef __cplusplus
}
#endif
#endif
```

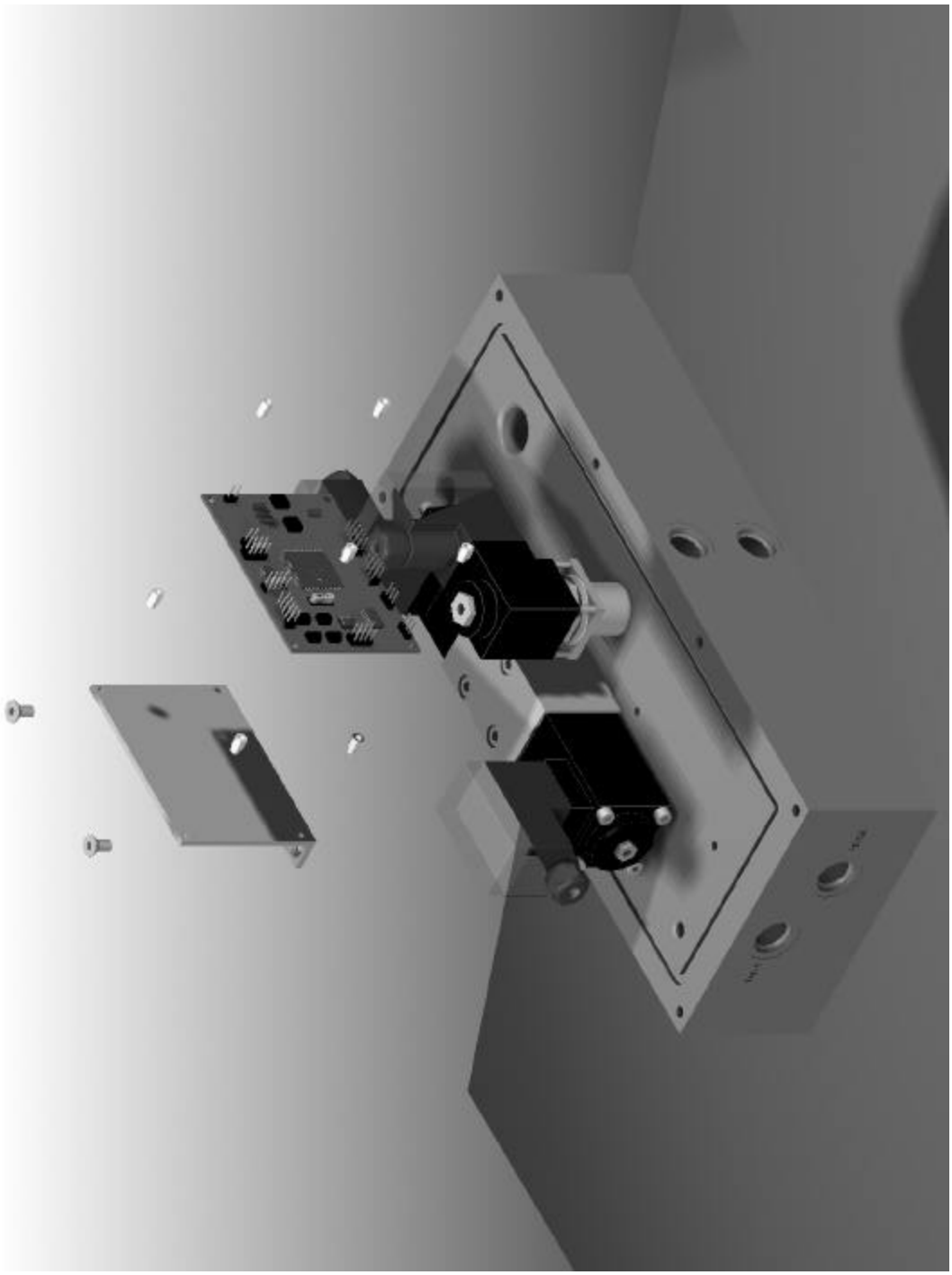
Appendix G

Valve Pack









Appendix H

Baseline System

C Code:

```
/*      Put It All Together.c       */
/*      PROJECT PUT IT ALL TOGETHER         */

#include "port.h"
#include "arch.h"
#include "stdlib.h"
#include "io.h"
#include "fcntl.h"
#include "dac.h"
#include "time.h"
#include "assert.h"
#include "bsp.h"
#include "gpio.h"
#include "sci.h"
#include "string.h"
#include "adc.h"



/************************** GLOBAL VARIABLES     ***************************/
int SCI0;                                                                   //
        Serial Port 0 definition
int PortD;                                                                  //
        GPIO Port D definition
int TurnsCounter=0;                                                         //
        GPIO Counter
struct timespec QuartSecond = {0, 250000000};       //      Quarter second delay time
int CCFlag;                                                 // Synchronization
flag for ADC Read
struct sigevent Timer1Event;                            //      Timer Event
Timer1 - ADC Read
timer_t Timer1;                                                             //
        Timer for ADC Read
struct itimerspec Timer1Settings;                       //      Timer1 settings: initial
value, repeat value
struct timespec HalfSecond = {0, 500000000};        //      Half second delay time
int     n=0;                                                                //
        ReceiveString construction integer
int     m=0;                                                                //
        ReceiveString indicator integer
static int dacDevice;                                               //      DAC
device handle
static UWord16  DACOut[1];                                          // DAC Output
word


/***********************     GLOBAL STRINGS
        ********************************/
```

```
char    TurnsCounterString[5]="C0000";                  // Counter serial output string
char    CreatedString[4]="0000";                        // Created string return from function
char    ADCString[5]="T0000";                                   // Torque serial output
string
char    ASideString[4]="A000";                          // Pressure serial output string
char    BSideString[4]="B000";                          // Pressure serial output string
char    PressureString[5]="P0000";                              // Pressure serial output
string


/*********************  FUNCTION DECLARATIONS    *************************/
static void COUNTRECEIVED_ISR(void);
void ConfigGPIOPort(void);
void CreateStringFrmDigits(int NumberToConv);
void ConfigSerial(void);
void CC_CallBack( adc_eCallbackType type, adc_tSampleMask causedSampleMask );
void ConfigADCPort(void);
void ReadADCChannel(void);
void ConfigTimer(void);
static void Timer1ISR(union sigval);
void sciRxCallBack(void);
void SetDACOutput(void);
void ConstructASideString(char temp1[1]);
void ConstructBSideString(char temp1[1]);
void ConstructPressureString(char temp1[1]);




/************************        ADC Channel 0 Configuration        *********************/
static const adc_sState sadc0 = {

 /* AnalogChannel      = */  ADC_CHANNEL_0,
 /* NumSamplesPerScan  = */  1,

 /* OffsetRegister     = */  0,
 /* LowLimitRegister   = */  0,
 /* HighLimitRegister  = */  0,
 /* ZeroCrossing       = */  0,

};


/************************        ADC Channel Structure     ************************/
struct ChannelData
{
   UWord16    handle;
   ssize_t    len;
   Frac16     Buf[8];
};
```

```
struct ChannelData  Data0;              //ADC Channel 0 Declaration




/**********************FUNCTION MAIN
            ***************************************/
/*****************************************************************************/
void main(void)
{
            int n=0;


            /* Get handle to DAC device */
            dacDevice = open(BSP_DEVICE_NAME_DAC, NULL);

            /*          Configure serial port          */
   ConfigSerial();

            /* Configure GPIO port      */
            ConfigGPIOPort();

            /*          Configure ADC port          */
            ConfigADCPort();

            /*          Configure timer for ADC read          */
            ConfigTimer();

   /* Install COUNTRECEIVED_ISR function as an GPIO interrupt service */
            archInstallISR(&(pArchInterrupts->MpioD), COUNTRECEIVED_ISR);


   /* Main loop */

   while(1)
   {
   }

}




/**********************FUNCTION COUNTRRECEIVED_ISR
            ****************************/
```

```
/*                                                                      */
/*          This function is called upon reception of a GPIO interrupt from pin D,1.  */
/*  It clears the interrupt, increments the turns counter, and calls the        */
/*  function CreateStringFrmDigits() to update the Counter serial string     */
/*                                                                      */
/************************************************************************/
static void COUNTRECEIVED_ISR(void)
{
        char temp1[1]="C";

        ioctl(PortD, GPIO_CLEAR_INTERRUPT_PEND_REGISTER, gpioPin(D,0));

        ioctl(PortD, GPIO_INTERRUPT_DISABLE, gpioPin(D,0));

        TurnsCounter++;

        CreateStringFrmDigits(TurnsCounter);

        TurnsCounterString[0]=temp1[0];
        TurnsCounterString[1]=CreatedString[0];
   TurnsCounterString[2]=CreatedString[1];
   TurnsCounterString[3]=CreatedString[2];
   TurnsCounterString[4]=CreatedString[3];

   nanosleep(&QuartSecond, NULL);

        ioctl(PortD, GPIO_INTERRUPT_ENABLE, gpioPin(D,0));

}



/*********************FUNCTION ConfigGPIOPort            ***************************/
/*                                                                      */
/*          This function configures GPIO port D: opens port, setas general purpose   */
/*  I/O, and enable interrupts.  It also initializes the counter serial         */
/*  string.                                                             */
/*                                                                      */
/*                                                                      */
/************************************************************************/
void ConfigGPIOPort(void)
{
        char temp1[1]="C";
        char temp2[1];

        *temp2=0x30;
```

```
        TurnsCounterString[0]=temp1[0];
        TurnsCounterString[1]=temp2[0];
  TurnsCounterString[2]=temp2[0];
  TurnsCounterString[3]=temp2[0];
  TurnsCounterString[4]=temp2[0];

        PortD = open(BSP_DEVICE_NAME_GPIO_D, 0);

        ioctl(PortD, GPIO_SETAS_GPIO, gpioPin(D,0));

        ioctl(PortD, GPIO_INTERRUPT_ENABLE, gpioPin(D,0));

}




/*********************FUNCTION CreateStringFrmDigits **********************/
/*                                                                         */
/*      This function will create a 4 character string from a 4 digit number.    */
/*                                                                         */
/***************************************************************************/
void CreateStringFrmDigits(int NumberToConv)
{

        int NumThous,NumHuns,NumTens,NumOnes;
        char string_thous[1]="0";
        char string_huns[1]="0";
        char string_tens[1]="0";
        char string_ones[1]="0";

        NumThous=(NumberToConv/1000);
        NumHuns=((NumberToConv-(NumThous*1000))/100);
  NumTens=((NumberToConv-(NumThous*1000)-(NumHuns*100))/10);
  NumOnes=((NumberToConv-(NumThous*1000)-(NumHuns*100)-(NumTens*10)));

  NumThous=0x30+NumThous;
  NumHuns=0x30+NumHuns;
  NumTens=0x30+NumTens;
  NumOnes=0x30+NumOnes;

  *string_thous=NumThous;
  *string_huns=NumHuns;
        *string_tens=NumTens;
        *string_ones=NumOnes;

        CreatedString[0]=string_thous[0];
```

```
        CreatedString[1]=string_huns[0];
        CreatedString[2]=string_tens[0];
        CreatedString[3]=string_ones[0];

}



/**********************FUNCTION ConfigSerial    *************************/
/*                                                                      */
/*      This function configures serial port 0: opens port with 8 bit words,    */
/*  no parity, 9600 baud.  It also sets the receive interrupt callback          */
/*  function as sciRxCallBack(), and the read length at 1.                      */
/*                                                                      */
/************************************************************************/
void ConfigSerial(void)
{

        int SciReadLength;


        sci_sConfig SciConfig;      //  Declaration of Serial Port Config Structure

        /*      Definition of Serial Port Structure */
        SciConfig.SciCntl   = SCI_CNTL_WORD_8BIT | SCI_CNTL_PARITY_NONE;
        SciConfig.SciHiBit = SCI_HIBIT_0;
        SciConfig.BaudRate = SCI_BAUD_9600;

        /*      Open Serial Port 0 */
        SCI0 = open(BSP_DEVICE_NAME_SCI_0, O_RDWR | O_NONBLOCK, &SciConfig);

        /*      Serial Port Initialization Error */
        if (SCI0 == -1)
        {
                assert(!" Open /sci0 device failed.");

        }

        /* Set the data format for 8-bit characters
                and Clear the Read and Write buffers */
        ioctl(SCI0, SCI_DATAFORMAT_EIGHTBITCHARS, NULL);

        /* Set the Receive Callback function */
        ioctl(SCI0, SCI_CALLBACK_RX, sciRxCallBack);

        /* The SCI Rx CallBack function will be called by the SCI driver after
        one character is received by setting the read length to 1. */
```

```
        SciReadLength = 1;
        ioctl(SCI0, SCI_SET_READ_LENGTH, &SciReadLength);

}




/*********************FUNCTION CC_CallBack              ***************************/
/*
                                                                        */
/*      This function handles the ADC conversion complete interrupt and     */
/*      increments the syncronization flag to start another read.                   */
/*
                                                                        */
/*****************************************************************************/
void CC_CallBack( adc_eCallbackType type, adc_tSampleMask causedSampleMask )
{

   CCFlag = 1;

}




/*********************FUNCTION ConfigADCPort            ***************************/
/*
                                                                        */
/*      This function configures the ADC port: opens ADC channel 0 - according  */
/*      to structure sadc0, initializes the synchro flag, and starts the first      */
/*      read.
                                                                    */
/*
                                                                        */
/*****************************************************************************/
void ConfigADCPort(void)
{

        /*      Open ADC Port   */
        Data0.handle  = open(BSP_DEVICE_NAME_ADC_0, 0, &sadc0 );

   CCFlag = 0;                  //      Initialize synchro flag to zero
   ioctl( Data0.handle, ADC_START, 0 );     //      Start ADC reads

}
```

```
/*********************FUNCTION ReadADCChannel        ***************************/
/*                                                                              */
/*      This function is called byt Timer1ISR and reads the value from ADC      */
/*      channel 0.  If a number is read, it calibrates it for ft-lbs and        */
/*      calls the CreateStringFrmDigits() routine to construct the ADC serial   */
/*      string.  It then writes the ADC, counter, and pressure strings to the   */
/*      serial port.  Finally, the synchro flag is reset to 0 and another ADC   */
/*      read commences.                                                         */
/*                                                                              */
/********************************************************************************/
void ReadADCChannel(void)
{
  int     NumSend;
  char temp1[1]="T";

        Data0.len = read( Data0.handle, Data0.Buf, sizeof(Data0.Buf) );

  if( Data0.len > 0 )           //  If something was read at ADC channel 0
  {

        NumSend=Data0.Buf[0];    //          Set local int = to ADC channel 0 buffer

        /* Calibrate Data: ADC range 0-32559,theoretical ft-lb range 0-1000 ft-lbs */
        /* 32559/1000 = 32.559 */
        NumSend=NumSend/32.559;

        CreateStringFrmDigits(NumSend);

        ADCString[0]=temp1[0];
        ADCString[1]=CreatedString[0];
        ADCString[2]=CreatedString[1];
        ADCString[3]=CreatedString[2];
        ADCString[4]=CreatedString[3];

                Data0.len = 0;
        }

        write(SCI0, &ADCString, sizeof(ADCString));

        write(SCI0, &TurnsCounterString, sizeof(TurnsCounterString));

        write(SCI0, &PressureString, sizeof(PressureString));

        nanosleep(&QuartSecond, NULL);

        if( CCFlag > 0 )
  {
      CCFlag = 0;
```

```
        ioctl( Data0.handle, ADC_START, 0 );
    }

}



/**********************FUNCTION ConfigTimer    ***************************/
/*                                                                        */
/*      This function configures Timer1ISR which calls for an ADC read every     */
/*      quarter second.                                                   */
/*                                                                        */
/**************************************************************************/
void ConfigTimer(void)
{

        Timer1Event.sigev_notify_function = Timer1ISR;

        timer_create(CLOCK_AUX1, &Timer1Event, &Timer1);

        Timer1Settings.it_interval.tv_sec = 0;
        Timer1Settings.it_interval.tv_nsec = 250000000;
        Timer1Settings.it_value.tv_sec = 0;
        Timer1Settings.it_value.tv_nsec = 250000000;

        timer_settime(Timer1, 0, &Timer1Settings, NULL);

}



/**********************FUNCTION Timer1ISR       ***************************/
/*                                                                        */
/*      This function defines the timer interrupt configured by ConfigTimer      */
/*      It then calls ReadADCChannel.                                     */
/*                                                                        */
/**************************************************************************/
static void Timer1ISR(union sigval)
{

        ReadADCChannel();


}
```

```
/*********************FUNCTION sciRxCallBack              ***************************/
/*                                                                                  */
/*  This function is called by the receive buffer full interrupt.  Upon      */
/*          reading a "P", "A" or "B" from the serial line, the function will                   */
/*          construct the PressureString (which is echoed back over the serial line), */
/*          ASideString or BSideString over the next 4 reads.  It will then call the  */
/*          corresponding ConstructXXXXString function to assemble the string.       */
/*          Finally, after every read, it clears the receive buffer.                    */
/*                                                                                  */
/************************************************************************************/
void sciRxCallBack(void)
{

        char    tempP[1]="P";
        char    tempA[1]="A";
        char    tempB[1]="B";
        char tempstring1[1];

        n++;

        read(SCI0, &tempstring1, sizeof(tempstring1) );    // Read Pressure



        if(tempstring1[0]==0x50)
        {

                PressureString[0]=tempP[0];

                n=0;

                m=1;

        }

        else if(tempstring1[0]==0x41)
        {

                ASideString[0]=tempA[0];

                n=0;

                m=2;
```

```
        }

        else if(tempstring1[0]==0x42)
        {

                BSideString[0]=tempB[0];

                n=0;

                m=3;

        }


        if(m==1)
        {

                ConstructPressureString(tempstring1);

        }

        else if(m==2)
        {

                ConstructASideString(tempstring1);

        }

        else if(m==3)
        {

                ConstructBSideString(tempstring1);

        }

        ioctl(SCI0, SCI_CMD_READ_CLEA R, NULL);

}




/**********************FUNCTION SetDACOutput            ***************************/
/*                                                                                 */
/*  This function is called by sciRxCallBack and will construct an integer    */
/*          from the pressuere, a or b side string.  It will then calibrate the                */
/*          DACOutput value for a range of 0 - 2.574 VDC equivalent to a pressure                */
/*          setting of 0 - 3000 psi or a flow of 0-100 %.  Finally, it will set the   */
```

```
/*      proper ADC channel to that value.
                                */
/*
                                                                        */
/*************************************************************************/
void SetDACOutput(void)
{
        int temp1, temp2;


        DACOut[0]=0;

        if(m==1)
        {
                temp1=PressureString[1] - 0x30;

                temp2=1000*temp1;

                temp1=PressureString[2] - 0x30;

                temp2=temp2 + 100*temp1;

                temp1=PressureString[3] - 0x30;

                temp2=temp2 + 10*temp1;

                temp1=PressureString[4] - 0x30;

                temp2=temp2 + temp1;

                if(temp2>3000)
                {
                        temp2=3000;
                }

                temp2=(temp2*65535)/3000;

                DACOut[0]=temp2;

                /* Output pressure value on Channel A */
                ioctl(dacDevice, DAC_SET_CHANNEL_A, NULL);
                ioctl(dacDevice, DAC_WRITE_MODE_UPDATE, NULL);
                write(dacDevice, DACOut, sizeof(UWord16));

        }

        if(m==2)
        {
                temp1=ASideString[1] - 0x30;

                temp2=100*temp1;
```

```
		temp1=ASideString[2] - 0x30;

		temp2=temp2 + 10*temp1;

		temp1=ASideString[3] - 0x30;

		temp2=temp2 + temp1;

		if(temp2>100)
		{
			temp2=100;
		}

		temp2=(temp2*65535)/100;

		DACOut[0]=temp2;

		/* Output A-Side value on Channel B */
		ioctl(dacDevice, DAC_SET_CHANNEL_B, NULL);
		ioctl(dacDevice, DAC_WRITE_MODE_UPDATE, NULL);
		write(dacDevice, DACOut, sizeof(UWord16));

}

if(m==3)
{
		temp1=BSideString[1] - 0x30;

		temp2=100*temp1;

		temp1=BSideString[2] - 0x30;

		temp2=temp2 + 10*temp1;

		temp1=BSideString[3] - 0x30;

		temp2=temp2 + temp1;

		if(temp2>100)
		{
			temp2=100;
		}

		temp2=(temp2*65535)/100;

		DACOut[0]=temp2;

		/* Output B-Side value on Channel C */
		ioctl(dacDevice, DAC_SET_CHANNEL_C, NULL);
		ioctl(dacDevice, DAC_WRITE_MODE_UPDATE, NULL);
```

```
                write(dacDevice, DACOut, sizeof(UWord16));

        }

}



/*********************FUNCTION ConstructPressureString          ******************/
/*                                                                              */
/*  This function constructs the pressure string and once complete makes      */
/*        makes a call to SetDACOutput                                          */
/*                                                                              */
/*                                                                              */
/********************************************************************************/
void ConstructPressureString(char temp1[1])
{

        if(n==1)
        {

                PressureString[n]=temp1[0];

        }

        else if(n==2)
        {

                PressureString[n]=temp1[0];

        }

        else if(n==3)
        {

                PressureString[n]=temp1[0];

        }

        else if(n==4)
        {

                PressureString[n]=temp1[0];

                SetDACOutput();

                n=0;
```

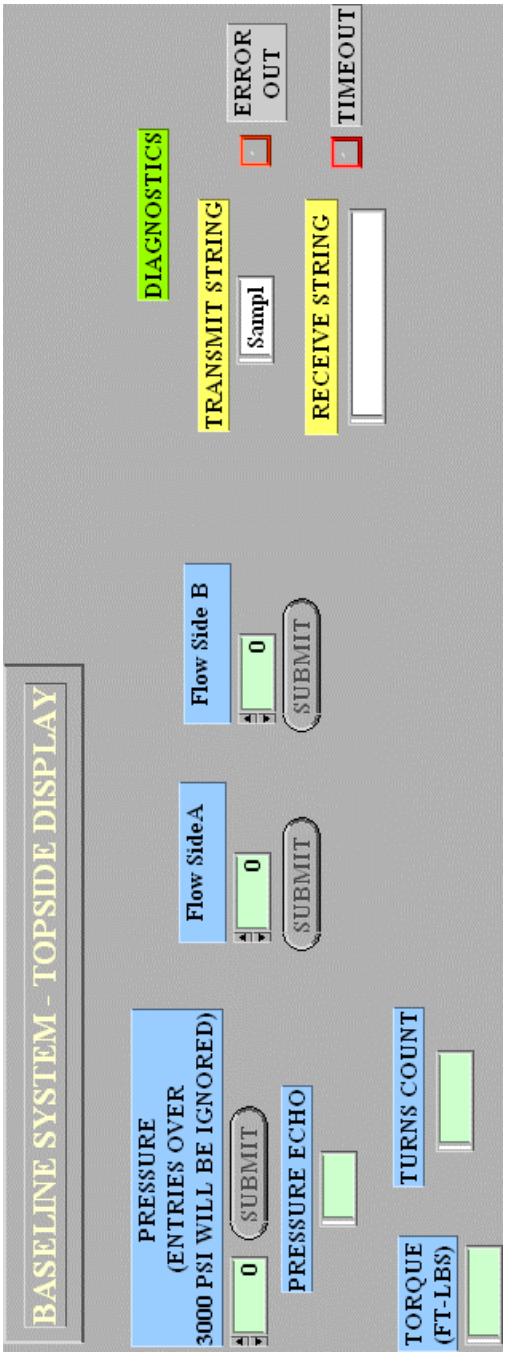
```
                m=0;

        }

}



/**********************FUNCTION ConstructASideString  ***********************/
/*                                                                          */
/*  This function constructs the A Side string and once complete makes      */
/*        makes a call to SetDACOutput                                      */
/*                                                                          */
/*                                                                          */
/****************************************************************************/
void ConstructASideString(char temp1[1])
{

        if(n==1)
        {

                ASideString[n]=temp1[0];

        }

        else if(n==2)
        {

                ASideString[n]=temp1[0];

        }

        else if(n==3)
        {

                ASideString[n]=temp 1[0];

                SetDACOutput();

                n=0;

                m=0;

        }

}
```

```
/*********************FUNCTION ConstructBSideString   **********************/
/*                                                                          */
/*  This function constructs the B Side string and once complete makes      */
/*          makes a call to SetDACOutput                                    */
/*                                                                          */
/*                                                                          */
/****************************************************************************/
void ConstructBSideString(char temp1[1])
{

        if(n==1)
        {

                BSideString[n]=temp1[0];

        }

        else if(n==2)
        {

                BSideString[n]=temp1[0];

        }

        else if(n==3)
        {

                BSideString[n]=temp1[0];

                SetDACOutput();

                n=0;

                m=0;

        }

}
```

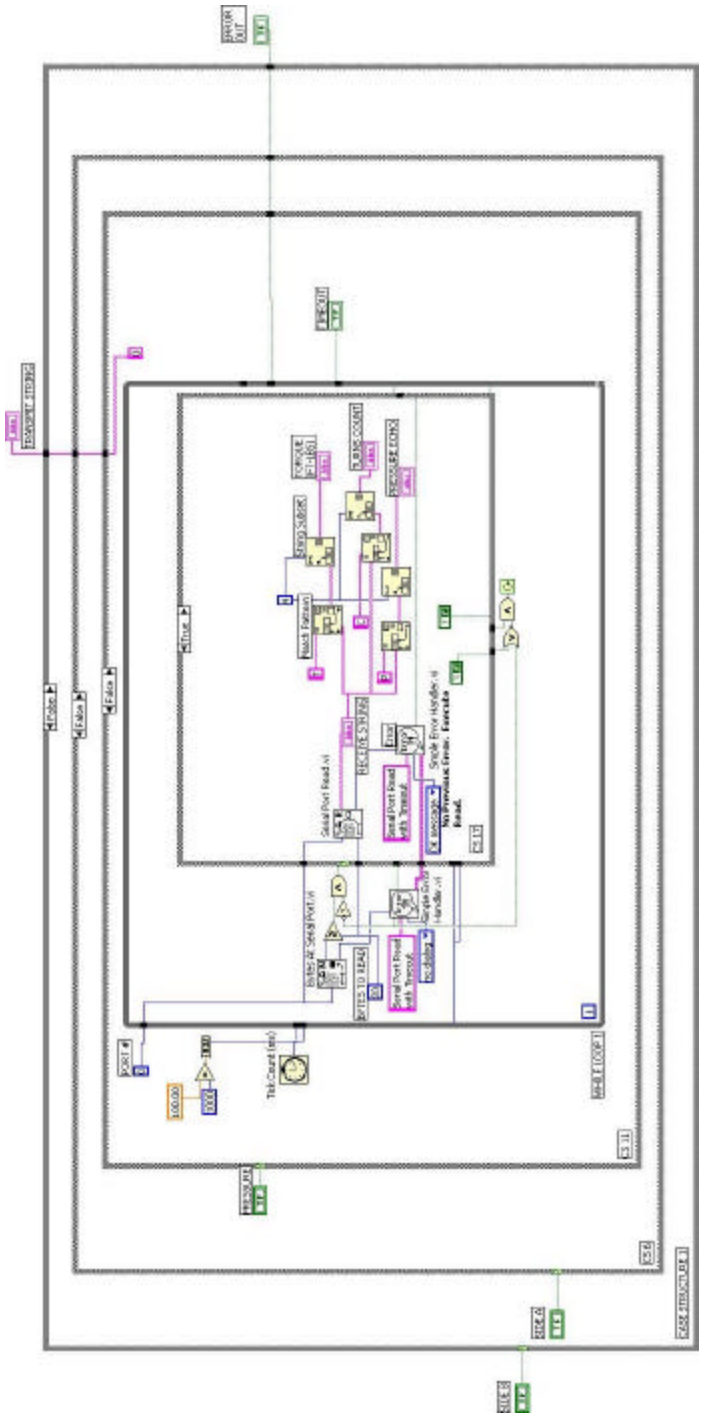
```
/*          File:       appconfig.h - External RAM          */
/*          Project:  PUT IT ALL TOGETHER.mcp          */

#ifndef __APPCONFIG_H
#define __APPCONFIG_H

#ifdef __cplusplus
extern "C" {
#endif
/*****************************************************************************
*
* Include needed SDK components by changing the #undef to #define
* Refer to config/config.h for complete list of all components and
* component default initialization.
*
*****************************************************************************/

#define INCLUDE_BSP          /* BSP support */

#define  INCLUDE_IO          /* I/O support */
#define  INCLUDE_TIMER       /* timer support */
#define  INCLUDE_SCI         /* SCI support */
#define  INCLUDE_ADC         /* ADC support */
#define  INCLUDE_GPIO        /* General Purpose I/O support */
#define  INCLUDE_DAC         /* DAC support */



/*****************************************************************************
*
* Overwrite default component initialization from config/config.h
*
*****************************************************************************/
#define  SCI0_SEND_BUFFER_LENGTH 20 // Setup transmit buffer length
#define  SCI0_RECEIVE_BUFFER_LENGTH 5 // Setup receive buffer length


#define GPR_INT_PRIORITY_20 1 /* Setup GPIO Port D ISR priority */

#define ADC_SCANMODE  ADC_SEQUENTIAL_ONCE         /* Set ADC Scan Mode*/

#define INCLUDE_ADCA_SAMPLE_0        /*Setup ADC Sample 0 */

/* user raw conversion callback */
#define ADC_RAW_CONVERSION_COMPLETE_CALLBACK  CC_CallBack

#ifdef __cplusplus
}
#endif
#endif
```

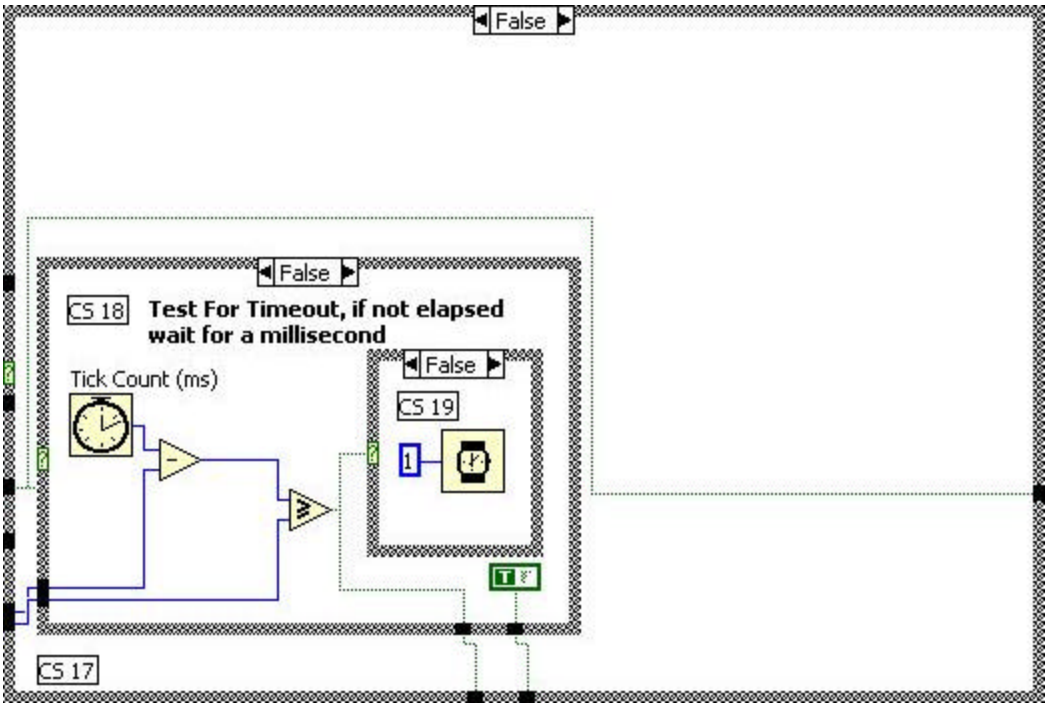
LabView:

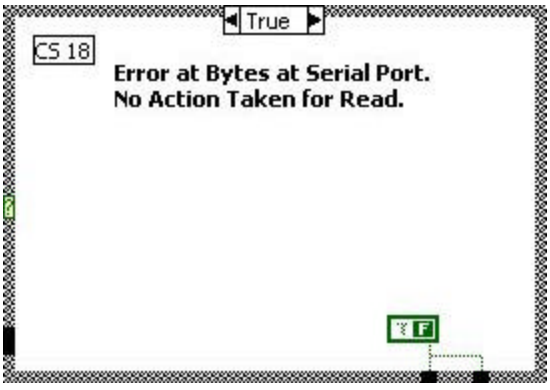
Front Panel

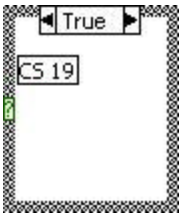


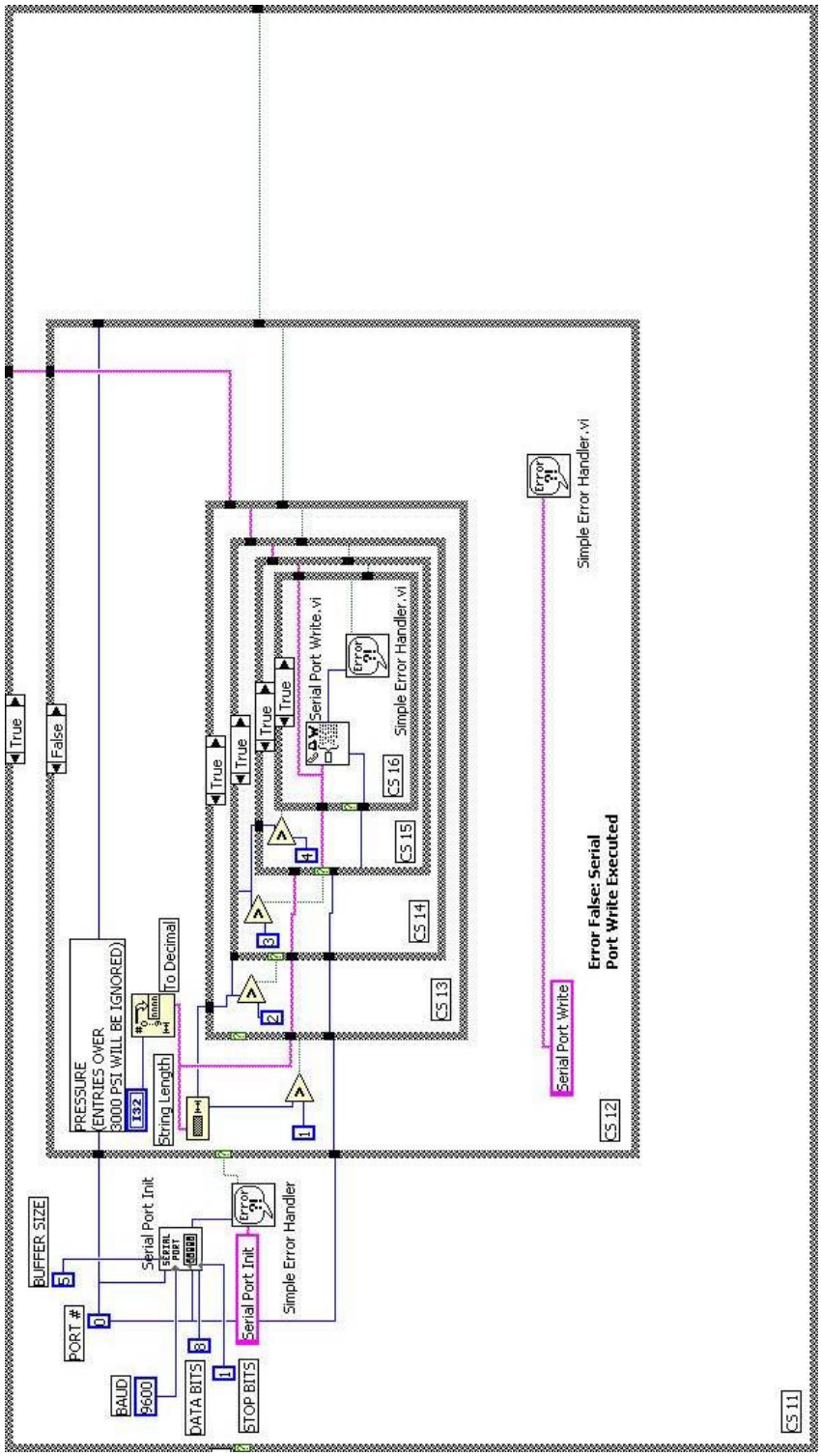
Block Diagram

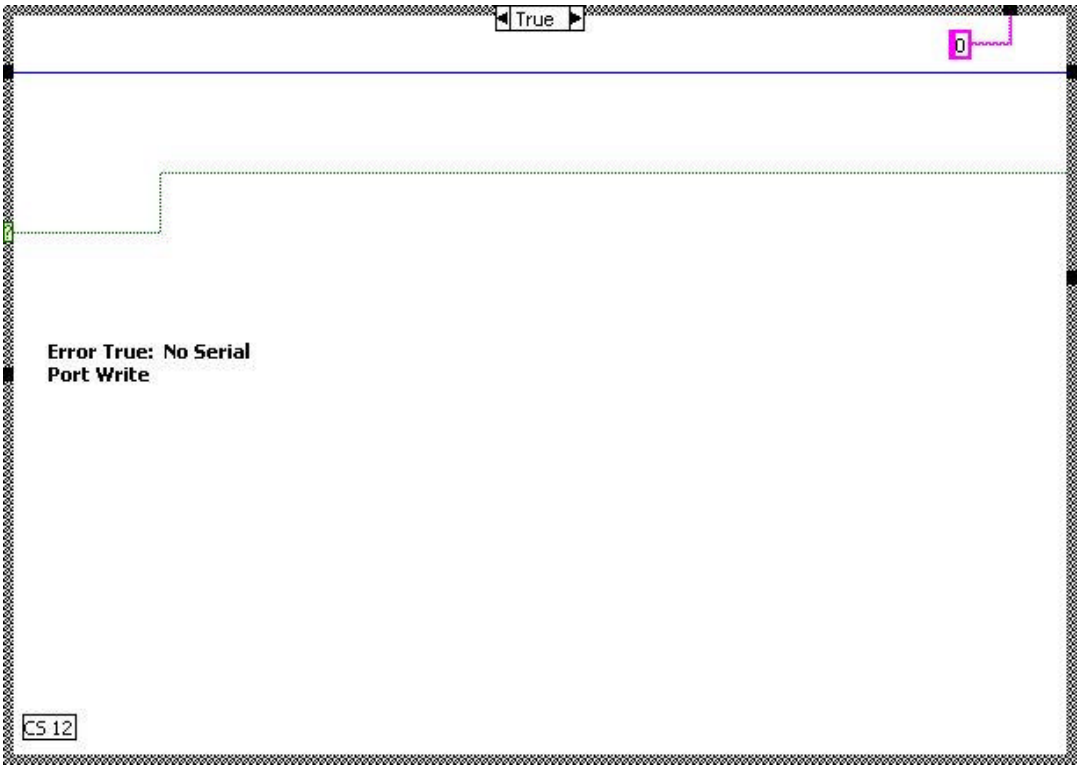


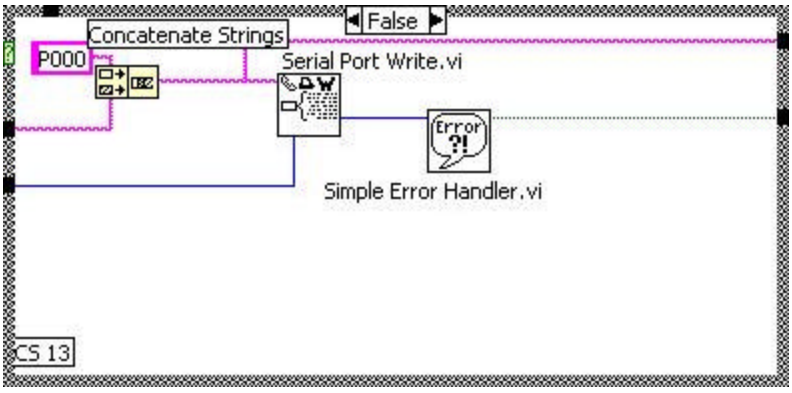

False
False
CS 18
Test For Timeout, if not elapsed
wait for a millisecond
Tick Count (ms)
False
CS 19
1
T
CS 17

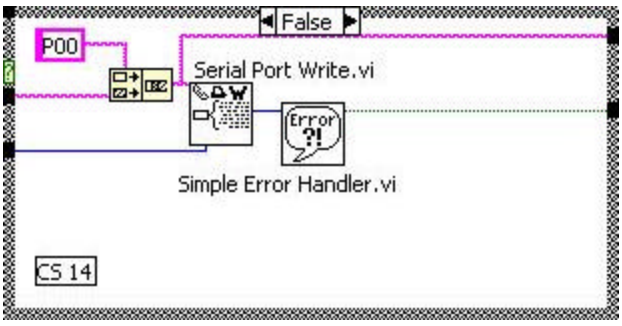

True
CS 18
Error at Bytes at Serial Port.
No Action Taken for Read.
F

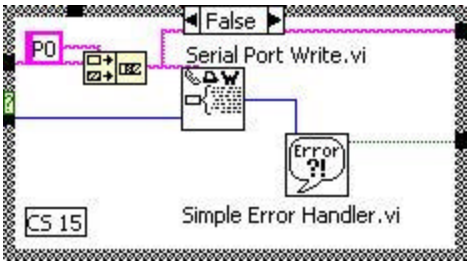

True
CS 19

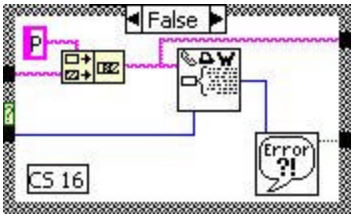

True
False
PRESSURE
(ENTRIES OVER
3000 PSI WILL BE IGNORED)
I32
To Decimal
String Length
BUFFER SIZE
5
PORT #
0
BAUD
9600
DATA BITS
8
STOP BITS
1
Serial Port Init
Serial Port Init
Simple Error Handler
Serial Port Write.vi
Simple Error Handler.vi
Serial Port Write
Simple Error Handler.vi
Error False: Serial
Port Write Executed
CS 11
CS 12
CS 13
CS 14
CS 15
CS 16

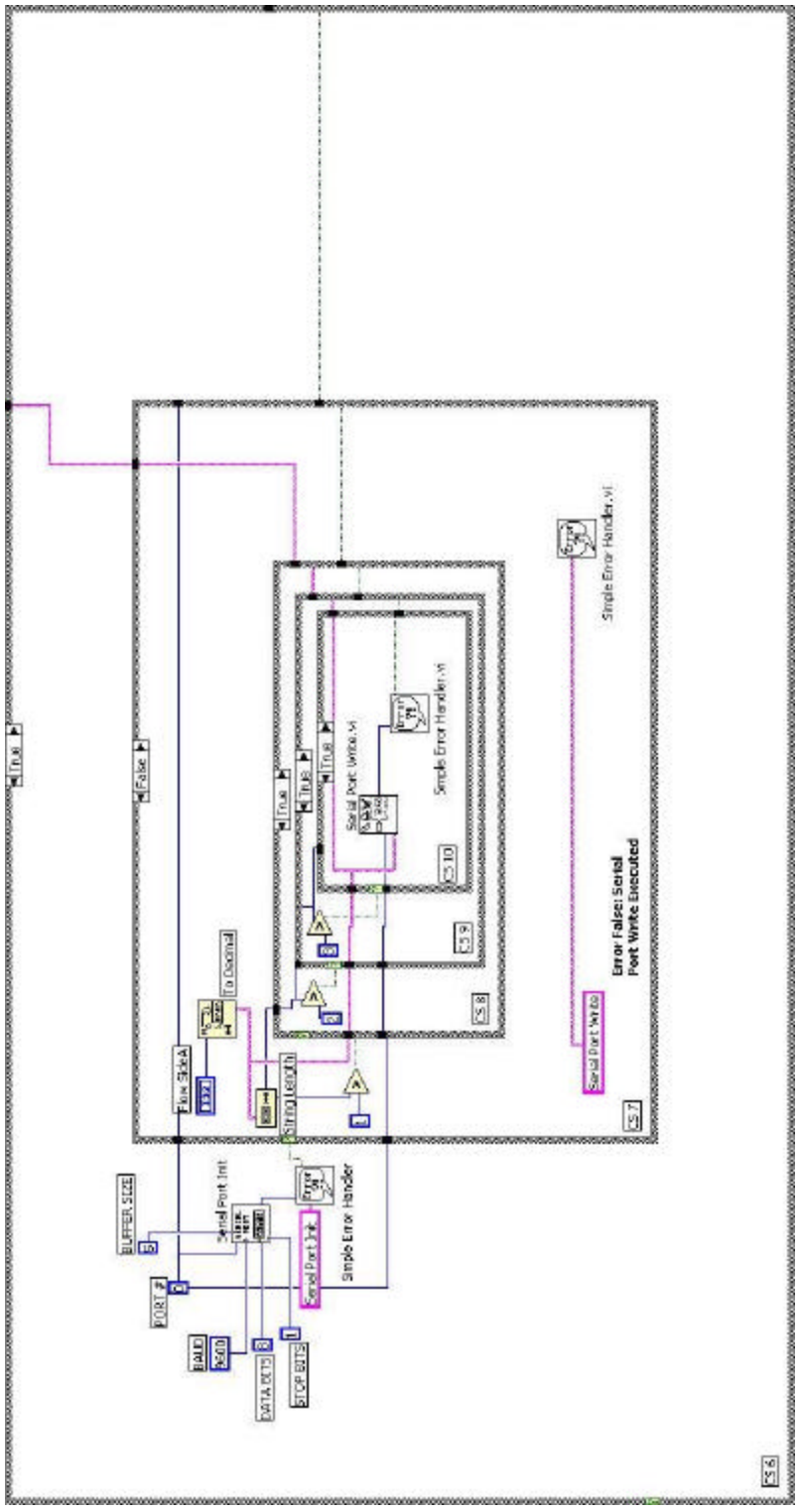

True
0
Error True: No Serial
Port Write
CS 12

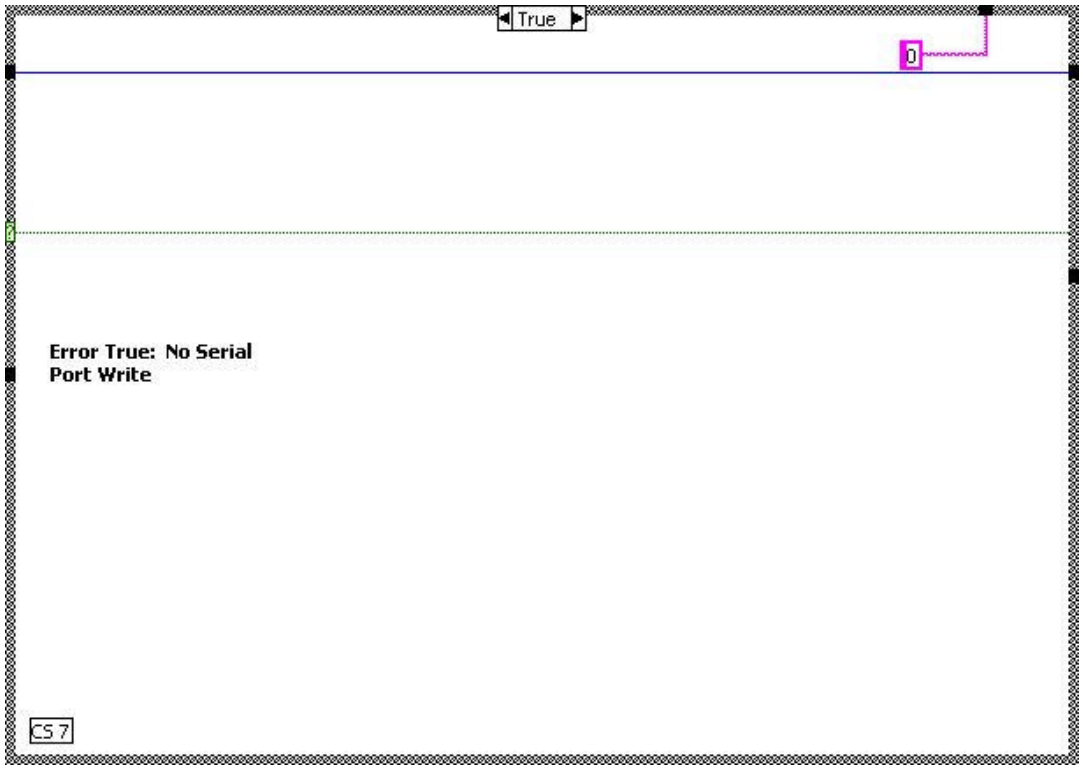

False
Concatenate Strings
P000
Serial Port Write.vi
Error
Simple Error Handler.vi
CS 13

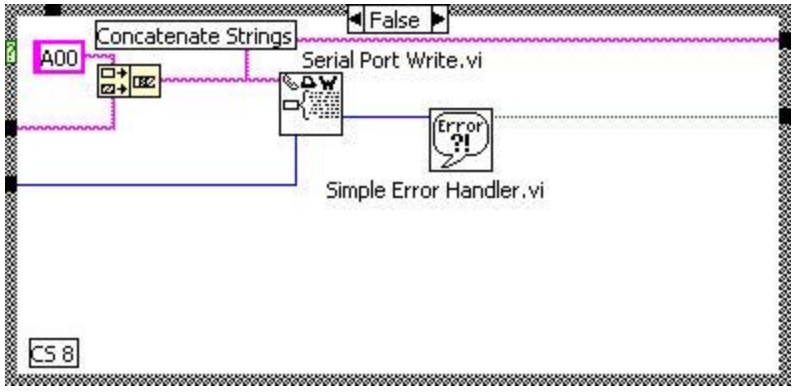

False
P00
Serial Port Write.vi
Error
Simple Error Handler.vi
CS 14

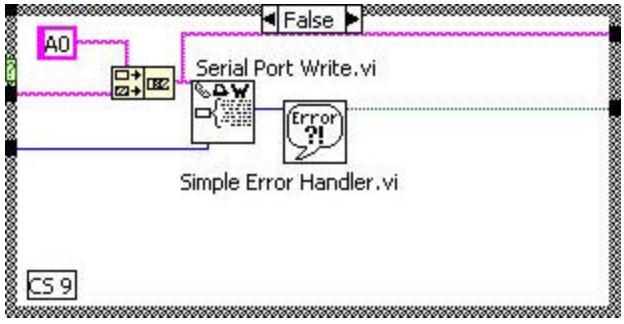

False
P0
Serial Port Write.vi
Error
?!
CS 15
Simple Error Handler.vi

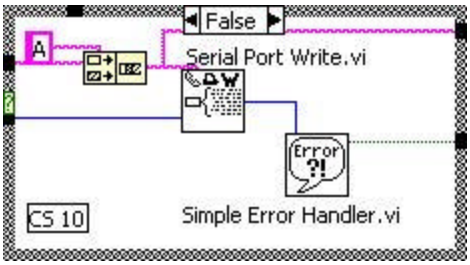

False
P
Error
?!
CS 16

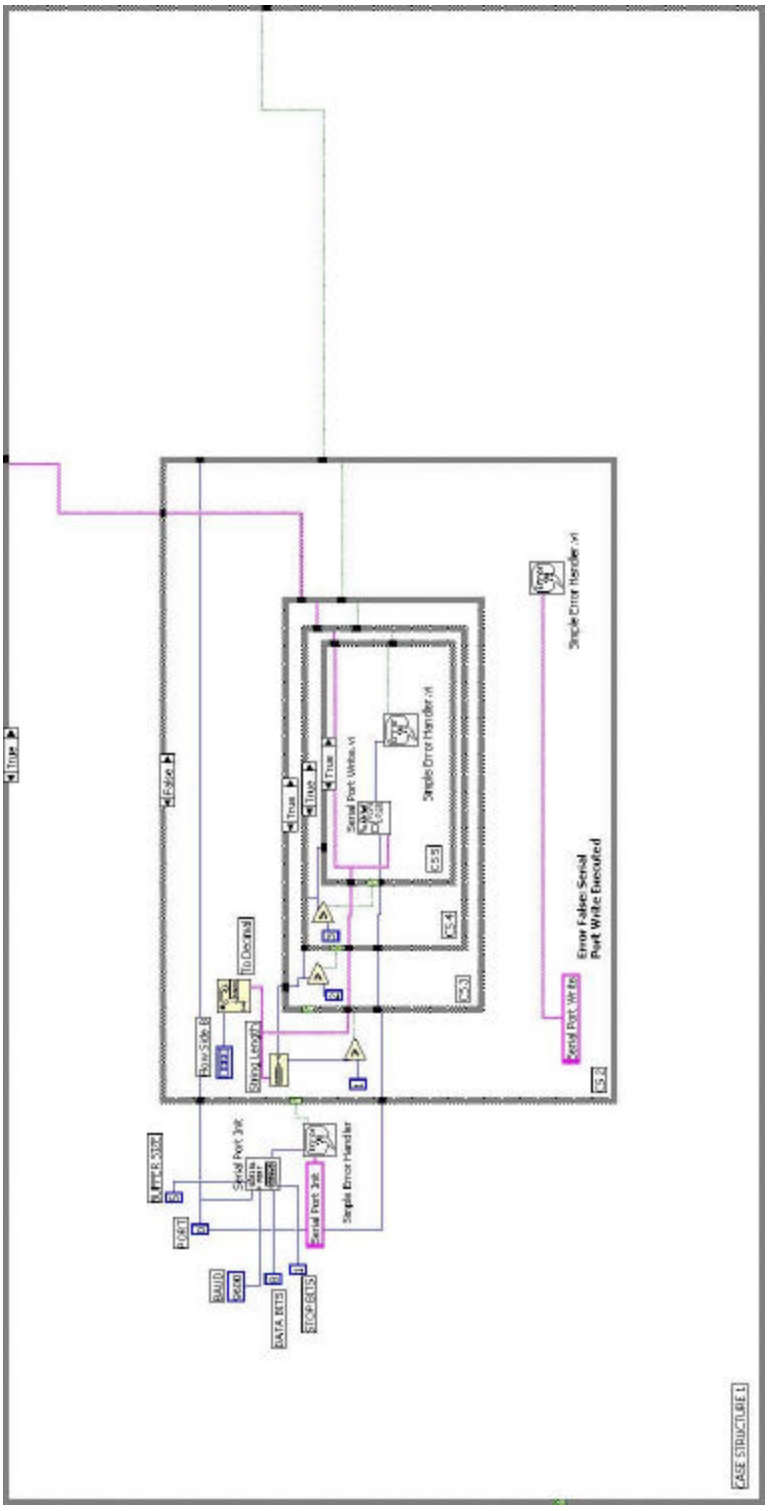

True
False
Simple Error Handler.vi
Error False: Serial
Port Write Executed
Serial Port Write
Serial Port Write.vi
Simple Error Handler.vi
To Decimal
Flow Ctrls
String Length
Serial Port Init
Simple Error Handler
BUFFER SIZE
PORT
BAUD
9600
DATA BITS
STOP BITS
CS 6
CS 7
CS 8
CS 9
CS 10

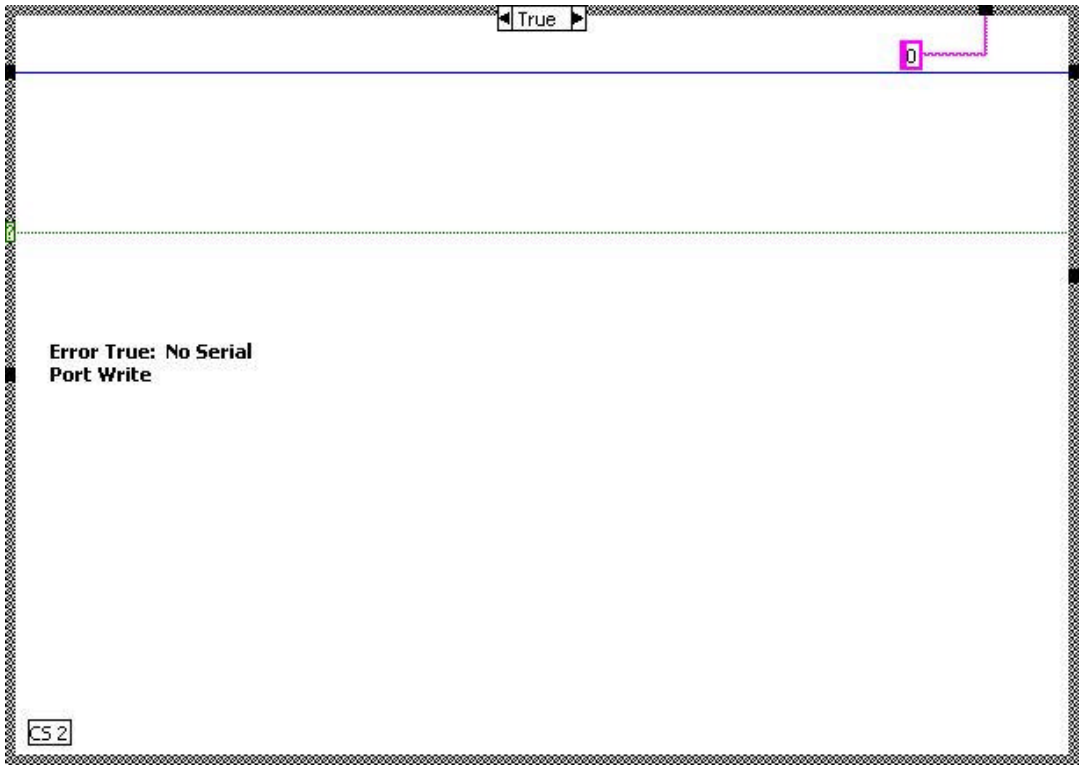

True
0
Error True: No Serial
Port Write
CS 7

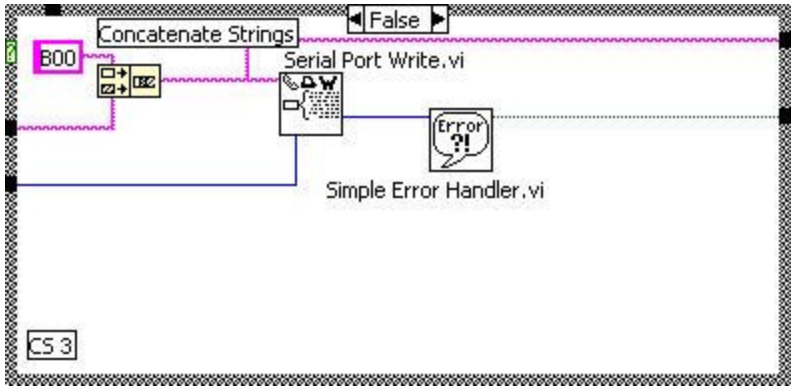

False
Concatenate Strings
A00
Serial Port Write.vi
Error
Simple Error Handler.vi
CS 8

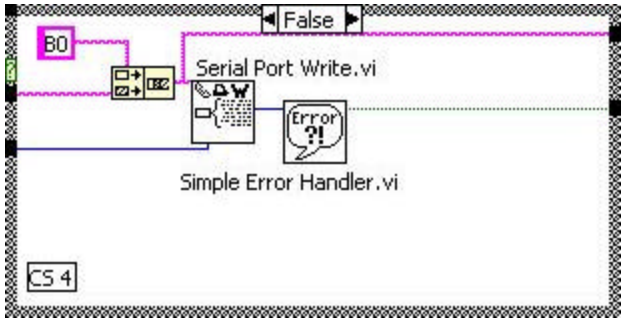

False
A0
Serial Port Write.vi
Error
Simple Error Handler.vi
CS 9

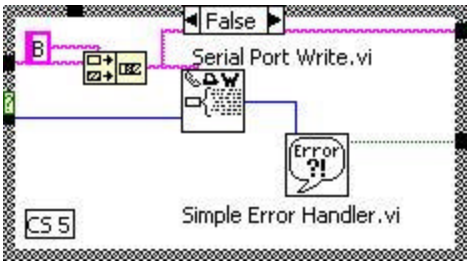

False
A
Serial Port Write.vi
Error
?!
CS 10
Simple Error Handler.vi


True
False
Simple Error Handler.vi
Serial Port Write.vi
Error False: Serial Port Write Executed
To Decimal
Serial Port Init
Serial Port Write
Simple Error Handler
BAUD
DATA BITS
STOP BITS
CASE STRUCTURE 1


True
0
Error True: No Serial
Port Write
CS 2


False
Concatenate Strings
B00
Serial Port Write.vi
Error
Simple Error Handler.vi
CS 3


False
B0
Serial Port Write.vi
Error
Simple Error Handler.vi
CS 4


False
Serial Port Write.vi
Error
?!
Simple Error Handler.vi
CS 5

Glossary

10BaseT	An Ethernet standard that specifies a 10 Mbps transfer rate (10) over a twisted pair line (T). This standard also uses a "star" bus configuration. Individual computers in the system are connected to common "hub" computers instead of a signal common communication line.[1]
ADC	Analog to digital converter
API	American Petroleum Institute
ARCNet	Originally developed by the Datapoint Corporation as a high- speed local area network (LAN) and was frequently found in office automation applications. Like Ethernet and Controller Area Network (CAN), ARCNet is a data-link layer technology with no defined application layer.
AUV	Autonomous underwater vehicle
BCH method	The Bose, Chaudhuri and Hocquenghem method is a type of CRC.
BOP	Blowout preventer. This large structure is placed over the wellhead during drilling operations and is comprised of multiple valves and seals. Its purpose is to create an isolated drilling environment that can be "shut-in" in case of an emergency such as a large release of natural gas or a high pressure pocket of oil. The BOP can actually sever the drill string and seal off the hole.

Buffer	A memory location reserved for the collection of a particular type of data.
Bus	A network bus is the transmission path that communication signals travel to move from one network point to another.
CAN	Control Area Network. Developed by Bosch, it is "a serial communications protocol which efficiently supports distributed real-time control with a very high level of security."[2]
Checksum	A checksum is a count of the number of bits in a transmission unit that is included with the unit so that the receiver can check to see whether the same number of bits arrived. If the counts match, it's assumed that the complete transmission was received. Both TCP and UDP communication layers provide a checksum count and verification as one of their services.
Christmas tree	Used in reference to the offshore oil industry, this applies to the structure placed over a subsea wellhead once drilling is completed and the production phase is set to begin. It consists of a series of valves used to control the flow out of the well.
CPU	Central processing unit

CRC	Cyclic redundancy checking is a method of checking for errors in data that has been transmitted on a communications link. A sending device applies a 16- or 32-bit polynomial to a block of data that is to be transmitted and appends the resulting cyclic redundancy code (CRC) to the block. The receiving end applies the same polynomial to the data and compares its result with the result appended by the sender. If they agree, the data has been received successfully. If not, the sender can be notified to resend the block of data.[3]
CSMA/CD	Carrier Sense Multiple Access/Collision Detection. Used by the Ethernet protocol to govern communication timing over its common bus. When two nodes attempt to transmit at the same time, a collision is declared that results in a "backoff time". By varying these times between nodes, one node will priority over another for bus access.[4]
DAC	Digital to analog converter
DeviceNet	A higher layer protocol (HLP) designed for use with the Motorola Control Area Network (CAN).[5]
DF1	An Allen-Bradley data-link layer protocol that combines features of subcategories D1 (data transparency) and F1 (two-way simultaneous transmission with embedded responses) of ANSI x3.28 specification. There are two categories of DF1 protocol, half-duplex protocol (master-

	slave communication), and full-duplex protocol (peer-to-peer communication).[6]
DSP	Digital signal processor
Ethernet	Ethernet was originally developed by Xerox, DEC, and Intel. An Ethernet LAN typically uses coaxial cable or special grades of twisted pair wires. There are several types of Ethernet standards but the most common one is 10BaseT that transmits at 10Mbps over twisted pair wires. Communication is over a common bus and is governed by Carrier Sense Multiple Access/Collision Detection method.[7]
EVM	Evaluation board or evaluation module.
Foundation Fieldbus	An all digital, serial, two-way communication system running at 31.25 kbit/s which interconnects "field" equipment such as sensors, actuators and controllers. Fieldbus is a Local Area Network (LAN) for instruments used in both process and manufacturing automation with built-in capability to distribute the control application across a network.[8]
GPIO	General Purpose I/O
GPM	Gallons per minute
GUI	Graphical user interface

Hall Effect	Named after Edwin Hall, who in 1879 observed that electrons moving longitudinally along a metal strip (under the influence of an electric field) will, if also subject to a magnetic field perpendicular to the plane of the strip, be deflected toward the side of the strip. Because of this, an excess of charge will build up one side of the strip. This Hall voltage is proportional to the strength of the magnetic field. That is, a plot of Hall voltage (or equivalently the electrical resistance of the material to the sideways current flow) versus field strength would be linear.[9]
HART	HART or "Highway Addressable Remote Transducer" was developed by Rosemount in the 1980's.[10] The HART Protocol supports two way digital communications for process measurement and control devices and is overlaid on a standard 4-20mA control signal. Applications include remote process variable interrogation, cyclical access to process data, parameter setting and diagnostics.[11]
HLP	Higher-layer protocol
IDE	Integrated development environment
IDE bit	Identifier extension
IEC	International Electrotechnical Commission

IEC 61131-3	Publication 61131 governs the IEC standard on programmable controllers. Part 3 "specifies syntax and semantics of programming languages for programmable controllers as defined in part 1 of IEC 61131."[12]
IEEE	Institute of Electrical and Electronic Engineers
IEEE 802.3	The IEEE specification for CSMA/CD model communications. The subcommittee that developed this standard based it on Ethernet.
I/O	Input/output. Refers to the capabilities of a microcontroller such as the ability and number of digital signals it can receive and transmit.
ISA bus	A 16 bit computer bus specified by the Industry Standards Association. This bus was common to the IBM AT computers and a modified version is used on the PC-104 form factor controllers.
ISO	International Organization of Standards
ISR	Interrupt service routine. An ISR is a program function that is called as the result of an interrupt or trigger.

Ladder logic	Or Ladder diagram is based on the graphical presentation of Relay Ladder Logic and is defined as one of two graphical programming languages under IEC 61131-3. The three main elements are relay, coil, and special function block.[13]
LAN	Local area network.
LED	Light emitting diode
LLC	Logical link control. One of two sub layers of the data link layer as defined by the OSI standard of networking.
LONWorks	Created by Echelon Corp and governed by the ANSI/EIA 709.1 Control Networking Standard. "The protocol provides a set of communication services that allow the application program in a device to send and receive messages from other devices over the network without needing to know the topology of the network." Similar to the CAN protocol in that "every device on a channel looks at every packet transmitted on the channel to determine if it is an addressee. If so, it processes the packet to see if it contains data for the device's application program or whether it is a network management packet."[14]
MAC	Media access control. One of two sub layers of the data link layer as defined by the OSI standard of networking.

Microcontroller	A microchip built for a particular control purpose. Typically runs an instruction set embedded in onboard memory that includes instructions for boot up, power modes, and the application to be run. Can have a wide range of I/O capabilities including timers, digital switching, analog I/O, serial communication, pulse width modulation, etc.
MODBUS	An application layer messaging protocol, positioned at level 7 of the OSI model that provides client/server communication between devices connected on different types of buses or networks. MODBUS® Protocol was developed by Modicon in 1979.[15]
MSCAN	Motorola Scalable Controller Area Network.
OLE	"Microsoft's framework for a compound document technology. Briefly, a compound document is something like a display desktop that can contain visual and information objects of all kinds: text, calendars, animations, sound, motion video, 3-D, continually updated news, controls, and so forth. Each desktop object is an independent program entity that can interact with a user and also communicate with other objects on the desktop. Part of Microsoft's ActiveX technologies, OLE takes advantage and is part of a larger, more general concept, the Component Object Model (COM) and its distributed version, DCOM. An OLE object is necessarily also a component (or COM object)."[16]

OPC	OLE for Process Control. "Based on Microsoft's OLE (now ActiveX), COM (component object model) and DCOM (distributed component object model) technologies, OPC consists of a standard set of interfaces, properties, and methods for use in process-control and manufacturing-automation applications. The goal of the standard is Plug-and-Play."[17] The standard is managed by the OPC Foundation consisting of 150 international members.
OSI	Open Systems Interconnection is a standard description or "reference model" for how messages should be transmitted between any two points in a telecommunication network. Its purpose is to guide product implementers so that their products will consistently work with other products. OSI was officially adopted as an international standard by the International Organization of Standards (ISO). Currently, it is Recommendation X.200 of the ITU-TS. OSI divides telecommunication into seven layers.[18]

PC 104

The PC/104 specification was developed by the IEEE in 1992 and is titled P996.1 Standard for Compact Embedded-PC Modules. The specification called for a reduced form factor of the IEEE P996 (draft) specification for the PC and PC/AT buses, for embedded applications. The key differences between PC/104 and the regular PC bus (IEEE P996) are[19]:

- Compact form-factor (3.6 by 3.8 inches)
- Unique self-stacking bus which eliminates the cost and bulk of backplanes and card cages
- Pin-and-socket connectors - rugged and reliable 64- and 40-contact male/female headers replace the standard PC's edge card connectors.
- Relaxed bus drive (6 mA). Lowers power consumption (to 1-2 Watts per module) and minimizes component count.

PCB

Printed circuit board

PDU

Power distribution unit. The PDU includes various power transformers, supplies, circuit breakers, and alarms to provide power and isolation to the ROV system.

PLC

Programmable logic controller

Plug & play	The ability to attach a piece of equipment to a computerized system without having to perform complicated hardware changes to make it work. The term was developed to describe modern peripherals that can be installed into a wide range of desktop computers with the associated driver software without having to manipulate dip switches and BIOS settings.
Processor	In this text refers to a microchip found in a desktop computer or laptop. Operation revolves around an operating system such as Windows, DOS, Linux, etc. which provides the user with a working environment. These chips are not designed to work by themselves but with a wide variety of peripherals such as external memory storage devices (hard drives, CD-ROMs), user input devices (keyboard, mouse), and graphical displays (monitor).
PROFIBUS	Process Field Bus is governed by IEC 61158. According to PROFIBUS International, the key features of PROFIBUS are speed, ease of use, versatility, economical, interoperability with plug and play, open, and standardized. It can be controlled by PLC-, PC-, or DCS-based systems.[20]
PWM	Pulse width modulation.

Reed switch	This device is a proximity sensor that detects the presence of a magnet. Inside the switch there are two ferromagnetic contacts. Introduction of a magnetic field by the presence of a magnet either attracts the two contacts in a normally open reed switch or repels the two contacts in a normally closed reed switch.[21]
ROV	Remotely operated vehicle. In this case, it is an underwater robotic vehicle that is operated by human pilots from a surface control station. An ROV "flies" through the ocean using propeller style thrusters and receives power and command signals via an armored umbilical to the surface.
RTR bit	Remote transmission request
RxBG	Background receive buffer in the MSCAN message buffering system.
RxF flag	Receiver full flag.
RxFG	Foreground receive buffer in the MSCAN message buffering system.
SBC	Single board computer.

SCADA	Supervisory control and data acquisition. "An industrial measurement and control system consisting of a central host or master (usually called a master station, master terminal unit or MTU); one or more field data gathering and control units or remotes (usually called remote stations, remote terminal units, or RTU's); and a collection of standard and/or custom software used to monitor and control remotely located field data elements. Contemporary SCADA systems exhibit predominantly open-loop control characteristics and utilize predominantly long distance communications, although some elements of closed-loop control and/or short distance communications may also be present."[22]
SDK	Software development kit
SOF	Start of frame
SRR bit	Substitute remote request
TCP	Transmission Control Protocol is a communication protocol used along with the Internet Protocol (IP) to send information over LANs, WANs, and the Internet. TCP is an alternative to the User Datagram Protocol (UDP) and, together with IP, is sometimes referred to as TCP/IP. TCP handles the disassembly and assembly of data packets as well as error checking. In the Open Systems Interconnection (OSI) communication model, TCP, like UDP, is in layer 4, the Transport Layer.[23]

Telemetry	"The wireless transmission and reception of measured quantities for the purpose of remotely monitoring environmental conditions or equipment parameters. The term is also used in reference to the signals containing such data."[24]
TMS	Tether management system.
Torque tool	rotary actuator intervention tool as defined in API Spec 17D Section 921.2f. It creates a rotary action that can be used for such applications as rotating a valve stem to the open or closed position.
TxE flag	Transmit empty flag.
UDP	User Datagram Protocol is a communication protocol used along with the Internet Protocol (IP) to send information over LANs, WANs, and the Internet. UDP is an alternative to the Transmission Control Protocol (TCP) and, together with IP, is sometimes referred to as UDP/IP. UDP does not disassemble and reassemble data packets but requires higher layer software to determine that the entire data message has arrived. As a result, UDP requires less processor overhead and is not designed to handle large data messages like TCP. In the Open Systems Interconnection (OSI) communication model, UDP, like TCP, is in layer 4, the Transport Layer.[25]

USB	Universal serial bus. According to the Universal Serial Bus Specification Revision 2.0; "The goal is to enable such devices from different vendors to interoperate in an open architecture. The specification is intended as an enhancement to the PC architecture, spanning portable, business desktop and home environments. It is intended that the specification allow system OEMs and peripheral developers adequate room for product versatility and market differentiation without the burden of carrying obsolete interfaces or losing compatibility."[26]
VME bus	The VerseModular Eurocard bus was designed as a master slave bus system to withstand high shock, vibration and temperatures. The standard specifies a circuit board called the Eurocard that comes in three different footprints.
WAN	Wide area network.
Work Class ROV	According to API specifications, a heavy work class ROV equals or exceeds the following dimensions: 86"x70"x95" and 5000 lbs.[27] This type of vehicle is typically equipped with multiple cameras and lights, two robotic manipulators, sonar, and various tools depending on the task at hand. Heavy work class ROVs are used for projects such as oceanographic research, offshore oilfield work, underwater construction projects, communications cable installation, and salvage work.

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